

The present invention concerns the treatment of water by biological means, and particularly a process for the biological purification of fresh or sea water containing dissolved solid organic materials (particles of various sizes) and dissolved mineral substances resulting from the decomposition of the said organic materials, by means of aerobic and anaerobic microorganisms functioning continuously in the same reaction space.

According to the process of the invention, the water is treated by means of aerobic microorganisms which break down the organic materials, the nitrogenous components of which are broken down in two main stages, which are ammonisation (deamination and ammonification) and nitrification (nitrosation and nitration), and by means of heterotrophic anaerobic organisms which reduce the nitrate ions released by the oxidation of the nitrogen compounds by using, as a source of organic carbon, some of the carbon compounds present in the reaction medium (denitrification by heterotrophic means).

Biological ammonisation and nitrification are well known processes, used industrially to mineralise the organic nitrogen compounds present in domestic waste water and in aquarium water.

Denitrification by heterotrophic means is also a well known process which is beginning to be applied industrially to making fresh water fit to drink and purifying aquarium water. It requires the presence of a carbon-containing substrate.

However, the process of the invention is not limited to the oxidation of organic nitrogen compounds or to the reduction of the nitrates present in the water to be treated. It is also capable of eliminating or neutralising organic compounds containing sulphur and phosphorus, and many aromatic compounds,

particularly those which result from the decomposition of vegetable pigments. However, the exact nature of the processes involved is still unknown to the applicant.

The process of the invention can be applied with the greatest advantages to water containing organic materials of natural origin. Thus the process of the invention has a particularly interesting application in the purification of the water in aquariums and basins, in respect of which it makes it possible to preserve the purity, transparency, absence of colouring and, in a more general sense, the integrity of its biological and physico-chemical properties. The present invention is suited to closed-circuit aquariums and in particular domestic aquariums of all sizes, to giant basins and aquariums for the public and to basins used for aquaculture.

It will be noted that the microorganisms responsible for ammonisation (deamination and ammonification) and nitrification require an oxygen-rich medium (an aerobic medium), whilst denitrifying heterotrophic microorganisms require an oxygen-deficient medium and an organic carbon substrate. It should also be noted that all these microorganisms can grow and act effectively only on the surface of a material which serves as a carrier for them. In consequence, the purification of the water containing organic materials and derived products by biological means requires, in order to take place:

- that the microorganisms be fixed to a carrier,
- that the "pollutants" (organic materials and derived products) contained in the treated water come into contact with the microorganisms fixed to the surface of their carrier (these contacts having to have a frequency as high as possible),
- that every decomposed "pollutant" (that is to say one that has been transformed into different products) quickly leaves the

area (site) where it has been transformed, and that it is rapidly replaced by another "pollutant" coming into contact with the microorganisms so as to be decomposed in its turn, and so on,

- that the microorganisms responsible for the ammonisation (deamination and ammonification) and nitrification are situated in an oxygen-rich medium (an aerobic medium),

- that the denitrifying heterotrophic microorganisms are situated in an oxygen-deficient medium and that they have an organic carbon substrate.

Thus the various known methods differ through the means used to fulfil the conditions set out above. The state of the art can be defined by the patents described below in their essential characteristics.

A wide variety of inorganic materials with different structures, textures, porosity, chemical composition, etc are used as a carrier for microorganisms. These may for example be clay, sand, gravel, expanded clay, macro or micro-porous carbon, etc. With a few exceptions (for example sintered glass, European Patent No 0155.669), these carriers are not covered by patents. This is particularly the case with carbonate materials of natural origin, such as sand of organic origin, Breton ameliorant, crushed coral and shells, etc, which are used in several processes (for example European Patent No 0133.405 and French Patent FR.A.2.490.623, because of their ability to neutralise the acid products released by the bacterial reactions and regulate the pH of the water (the buffer effect).

All the known processes use the same means for transporting the pollutants as far as contact with the microorganisms fixed on their carrier and to discharge the products resulting from their decomposition: the water circulates in contact with the material

which serves as a carrier for the microorganisms. In some cases, the water to be treated passes through the carrier which then constitutes a filtering mass (filtration by percolation): for example the NITREX process, registered trade mark, and patents EP 0096.170, EP 0133.405, DE.A.3.434.678, EP A 0201.924, FR.A.2.079.100, FR.A.2.490.623, DE.A.2.001.333 and). In other cases, the material which serves as a carrier for the microorganisms is placed in suspension (activated sludge; for example patents EP 0008.471 and EP 0070.592) or again agitated or mixed in the treated water (agitation reactors or fluidised bed reactors; for example the patent EP 0046.901). The main drawback of percolating filters is their unavoidable blocking which requires periodic cleaning operations or total or partial replacement of the filtering mass. The main drawback of the methods using activated sludges is that it is necessary, at the end of the process, to separate the purified water and activated sludge. It is important to note that, in all these processes, the water circulates in contact with the material serving as a carrier for the microorganisms.

Various means are used to create and maintain the aerobic conditions essential for the microorganisms responsible for ammonisation and nitrification. In some cases (activated sludge), bubbles of oxygen or of an oxygen-rich gas blown in at the base of the reactor serve both to oxygenate the treated water and to create a current having the effect of maintaining the sludge in suspension (for example EP 0070.592 and EP 0008.471). When it is a case of percolation reactors, the previously oxygenated water can pass through the filtering body sufficiently quickly for its oxygen concentration to remain sufficiently high throughout its passage (this is a case with the majority of aquarium filters); however, it is sometimes necessary to blow in oxygen or an oxygen-rich gas, for example at the base of the reactor, so that the bubbles rise while passing through the filtering mass, in the opposite direction to the water which is passing by gravity through this same

filtering mass (for example patents FR.A.2.490.623 and FR.A.2.079.100). Finally, in certain percolating filters functioning by trickling (for example the nitrification stage of the Minireef process, registered trade mark), the filtering body is not completely impregnated with water. In the latter case, the oxygen concentration of the water which is trickling through is maintained at a high value simply by contact with the air which is circulating freely, in the interstices of the filtering mass. It is important to note that in all these processes the aerobic conditions are created and maintained by the blowing in of oxygen or an oxygen-rich gas into the water to be treated, before and (or) during the treatment, or again by the free circulation of air in the interstices of the filtering mass. In no case is oxygen produced inside the material which serves as a carrier for the microorganisms.

In the methods bringing a filtering mass into play, the anaerobiosis conditions are created and maintained by isolating the filtering mass from the ambient air, by reducing the flow of water and by extending the path of the water inside the filtering mass (for example patents EP 0096.170, EP 0133.405 and EP 0154.105).

The aerobic processes (ammonisation and nitrification) require an oxygen-rich medium whilst, on the other hand, the process of denitrification requires an oxygen-deficient medium. These opposite requirements mean that it is difficult to associate and cause to work continuously, in the same reaction space, the different microorganisms which are responsible for these processes. Thus the majority of the known methods carry out simultaneously, in the same place, only one or other of the two categories of process set out above, so that it is in general necessary to associate several devices serving to implement complementary methods for the purpose of successively obtaining the mineralisation of the organic materials by aerobic means, and then the transformation, by anaerobic means, of the

substances which result from this mineralisation. However, some methods succeed in making aerobic microorganisms and anaerobic microorganisms cohabit and act simultaneously in an unpartitioned reactor.

According to the European Patent No EP 0008.471, this result is obtained, inside a reactor containing water mixed with an actuated sludge in suspension, by regulating the agitation and the supply of oxygen so as to create, in the same reaction space, aerobic areas and anaerobic areas, which the water to be treated passes through successively. The main disadvantages of this process lie in the fact that the constraints imposed for creating and maintaining the conditions essential for the functioning of the process are severe, and it is necessary, at the end of the process, to separate the purified water and activated sludge. It is important to note that the water to be treated passes successively through the aerobic and anaerobic areas, and that the substance which serves as a carrier for the various microorganisms used is an activated sludge maintained in suspension in the water to be treated.

Another known process consists of passing the water to be treated slowly through a filtering mass, consisting of a porous or fibrous material completely impregnated with water and isolated from the ambient atmosphere, containing aerobic microorganisms and anaerobic microorganisms. In this case, the breakdown of the organic nitrogenous materials by ammonisation and nitrification is accomplished in the surface layer of the filtering mass by the aerobic microorganisms which consume the oxygen contained in the water. Thus, during its movement, the water progressively loses the oxygen which it contains, up to the time when the concentration of this gas is sufficiently low to allow the biological denitrification process to take place. This method has two major drawbacks. Firstly, the rate of flow of the water must be controlled to avoid the denitrification process being interfered with by an excess or lack of oxygen

resulting respectively from an excessively slow or excessively rapid flow of the water through the filtering mass. If there is too much oxygen in the denitrification area, the denitrification is incomplete and nitrites are released. Secondly, the water which reaches the area where the denitrification takes place no longer contains any organic carbon substances. In fact, these carbon substances are mineralised in the oxygen-rich layer which the water has to pass through before coming into contact with the denitrifying bacteria. Because of this the denitrification which takes place is an autotrophic denitrification whose yield is low.

In order to mitigate the latter drawback, known processes use an organic carbon substance which is incorporated in the water to be treated and whose proportioning must be rigorously controlled (for example the Minireef system, registered trade mark). Other known processes use, as a filtering mass, porous materials in which an organic carbon substrate has been incorporated (for example the NITREX method, registered trade mark, Patent EP 0133.405, EP 0102.584 and DE.A.3.434.678), but it is then essential to replace this porous material as soon as the carbon substrate which it contains is exhausted.

In addition, the use of a filtering mass has an additional disadvantage which particularly concerns marine aquariums. This disadvantage lies in the fact that the mechanical filtration, consequent upon the passage of the water through the filtering mass, interferes with or prevents the growth of many filtering organisms, partly or completely eliminating the plankton animalcules and organic particles in suspension which constitute their main source of food.

Finally, it should be noted that, according to the American patent US 4.333.263, the purification by biological means of water containing organic materials and derived products is achieved without resorting to microorganisms. Nitrates and

other dissolved mineral substances are absorbed by algae cultivated on latticework frames contained in a tank in which the water to be treated circulates. These frames are withdrawn frequently and scraped in order to eliminate the soft parts of the algae and, in consequence, the nitrates and other mineral substances which they have absorbed and fixed. This method, known as the algal scrubber method, has the drawback of requiring frequent intervention to scrape and eliminate some of the algae cultivated. It is important to note that it does not use aerobic or anaerobic microorganisms.

DE.A.3.434.678 (H HOFFMAN); as the figures clearly show, this is a device of the percolator type in which the volume of water to be treated passes through the filtering mass. The arrows shown in the figures are indicative. For reasons of safety, a bypass can shunt the filter to the chamber 5. There is no volume of confined water, and no treatment of the water by diffusion.

EP A-0-201.924: this patent describes a device in which the water passes through a filtering mass by percolation. There is therefore a circulation of the water. A clarification installation for purifying residual or organic water comprises a tank with an inlet pipe, a discharge pipe and an extraction pipe for the excess sludge. In the tank, which is constructed with an external surface which is as small as possible, per unit volume, a submerged assembly is disposed, subdivided into areas consisting of a certain number of individual units placed one above the other. In the area of the bottom of the tank, in the form of a funnel, an aeration system is disposed. The contents of the reservoir is circulated in the opposite direction to the ascending gas bubbles diffused by the aeration system, through a duct by means of a built-in pump. A movable measuring probe, movable inside a sounding tube, makes it possible to monitor the processes which take place in the different areas of the submerged assembly. With suitable coordination of the gas flow, the rate of flow of the residual water and the resistance

offered to the flow by the submerged unit, it is possible to set up differentiated conditions, for example aerobic, "optional" and/or anaerobic, in the individual areas of the submerged unit. The fact that the differentiated conditions are optional indicates that this is a case not of diffusion but of percolation.

FR.A.2.079.100: this patent describes a process for eliminating organic pollutants contained in the water, characterised by the fact that the water to be purified is passed through a filter bed consisting of a filling of a porous material having a specific active surface of between 10 and 400 square metres per gram, the said filter bed containing an aerobic bacterial population, under the action of which, under aerobic conditions within the filter bed, there develop phenomena of decomposition of the organic pollutants, with the introduction into the water being purified, during its filtration, of a quantity of oxygen sufficient to maintain the bacterial population in the aerobic state, depending on the pollutant content and the quantity of water to be purified.

FR.A.2.490.623: this patent describes a process for treating water in closed-circuit aquaculture systems, characterised in that it consists of passing the water through a filter bed of solid material into which an oxygen-containing gas is injected, so as to achieve, in a single stage, elimination of the nitrogenous pollution, oxygenation compensating for the consumption of oxygen, and, if necessary, elimination of the solid waste by filtration, the respective flow rates of gas containing oxygen and of water to be treated through the layer of solid material being such that the pH of the water is maintained at between 5 and 9.

DE.A.2.001.366: a filter based on algae and plants for filtering substances in suspension in aqueous solutions. The top layer of the filter bed consists of fibrous algae, which are maintained

loosely between two sieve plates. The bottom layer, the benthic layer, is generated from substances in suspension which have been intercepted.

DE.A.3.434.678: a method and device for eliminating albumin and its breakdown products in water. In a process for eliminating albumin and its breakdown products, in waste water, a filtering medium having a large contact surface is sprayed with the water to be purified. In order to be able to eliminate also, in particular, the nitrate present in the water, an inert carrier substance is used as the filtering material, such as a material based on a synthetic substance, preferably a cellular plastic material or foam, "Blähton" or other similar product, which contains products of bacteriophilic foods such as lactose and/or dextrose and/or phthalic ester or equivalent products, and which releases these products slowly over a long period of time, so that the carrier matter constitutes a substrate favourable for establishing colonies of bacteria. In the filtering material, an aerobic reaction area and an anaerobic reaction area are arranged, so that inside the filtering material it is possible to achieve the development of a nitrification process and of a denitrification process.

All these patents describe devices for filtrating by percolation (the water passes through a filtering mass) rather than by DIFFUSION.

The aim of the present invention is to remedy all these drawbacks by creating the first biological process, capable of achieving simultaneously and continuously, in a single reaction space, all the functions which make it possible completely to purify water containing solid and dissolved organic materials (particles of various sizes) and dissolved mineral substances resulting from the decomposition of the said organic materials, and being able to be implemented by means of a simple device capable of functioning without

dismantling. In the remainder of the text, the solid organic materials are designated by the terms "organic particles" and the mineral substances resulting from the decomposition of the said organic materials are referred to as "dissolved pollutants".

The technical characteristics of the process of the invention are as follows:

The process for the biological purification of fresh or sea water containing solid and dissolved organic materials and the dissolved mineral substances resulting from the decomposition of the said organic materials, and particularly of aquarium and aquaculture basin water, using the action of aerobic and anaerobic microorganisms having the property of decomposing the organic materials and neutralising the dissolved pollutants, the water is treated inside one or more means serving as reactors, and characterised by the fact that it uses one or more reactors (tanks) inside which the water is treated by DIFFUSION and the action of aerobic microorganisms and anaerobic microorganisms. Each reactor has, inside it, a main reaction space formed by a porous or fibrous substance, serving as a carrier for the various microorganisms used, which forms a thick partition, interposed between the volume of water to be treated and one or more volumes of confined water, the said main reaction space has means for maintaining concentration gradients of the various dissolved substances suitable for creating and maintaining the said diffusion.

a) The main reaction space is formed so that it comprises two interfaces in contact, respectively, with the oxygen-rich water to be treated and with a volume of confined oxygen-deficient water;

b) The main reaction space comprises, in its thickness, several adjacent reaction zones, an oxygen-rich zone adjacent to the

interface in contact with the water to be treated, an oxygen-deficient zone adjacent to the interface in contact with the confined water, and an intermediate zone.

c) The oxygen-rich reaction zone adjacent to the interface in contact with the water to be treated contains aerobic microorganisms which have the property of decomposing organic materials, and in particular aerobic microorganisms which have the property of completely mineralising the nitrogen compounds (transformation into nitrates).

d) The oxygen-deficient reaction zone, adjacent to the interface in contact with the confined water, contains anaerobic microorganisms which have the property of neutralising the dissolved polluting materials (transformation into innocuous materials), and in particular heterotrophic anaerobic microorganisms which have the property of completely reducing the nitrates (reduction of the nitrates to nitrites, and then of the nitrites to molecular nitrogen) and nitrites in the water to be treated.

e) The intermediate zone contains a mixture of aerobic and anaerobic microorganisms.

f) The confined water volume is in darkness.

The porous or fibrous material serving as carrier for the aerobic or anaerobic microorganisms preferably consists of a carbonate material having a buffer effect and having the effect of correcting the pH of the water.

The material consists of crushed coral.

The porous or fibrous material contains microalgae fixed in the thin surface layer adjacent to the interface in contact with the water to be treated; this interface is brightly illuminated.

Small detritivorous burrowing organisms are introduced into the body of the porous or fibrous substance.

For optimum functioning of the process of the invention, it is essential that, in the confined oxygen-deficient water volume, the concentration of this gas be maintained at approximately one milligram per litre of water, by a means of regulation.

The main reaction space is used for creating concentration gradients which structure the interior of each reactor (gradients of oxygen, nitrogen, carbon dioxide, ammonium ions, nitrites, nitrates, calcium and other dissolved substances).

This process uses some of the organic materials present in the water to be processed as a carbon-containing substrate essential for the heterotrophic denitrifying microorganisms.

This process uses means for preventing the light from reaching the volume of confined water and illuminating the interface of the porous or fibrous substance in contact with the said volume of confined water and for preventing any release of oxygen by photosynthesis.

The device for implementing the process consists of:

- one or more reactors (tanks) inside which the water is treated by DIFFUSION and the action of aerobic microorganisms and anaerobic microorganisms,
- each reactor has, inside it, a main reaction space formed by a porous or fibrous material serving as a carrier for the various microorganisms used, and which forms a thick partition interposed between the volume of water to be treated and one or more volumes of confined water.

The partition has, in its body, several reaction zones: a zone supersaturated with oxygen, occupied by microalgae and aerobic microorganisms; an oxygen-rich zone, occupied by aerobic microorganisms; an oxygen-deficient zone occupied by anaerobic microorganisms; an intermediate zone, in which aerobic microorganisms and anaerobic microorganisms are found.

The interior of each reactor includes one or more thick partitions, attached by their ends to the walls of the reactor.

The device has a thick horizontal partition.

The device has a thick vertical partition (or partitions).

The device has a thick inclined partition (or partitions).

The interior of each reactor has one or more thick partitions which are not attached to the walls of the reactor and form one or more cavities containing the confined water.

The porous or fibrous substance forming the partition and serving as a carrier for the various microorganisms used is, preferably, a carbonate material having a buffer effect and having the effect of correcting the pH of the water.

The partition consists of sand or gravel forming a layer between two grids.

The volume or volumes of confined water may comprise a means of regulating the dissolved oxygen concentration, which must be 1 mg/l.

The means of regulating the dissolved oxygen concentration, which must be between 0.5 and 1 mg/l, can be a flow of water which passes, in small quantities, through the said volume or volumes of confined water, the said flow being able to come,

through a pipe, from the volume of water to be treated and return through another pipe to this same volume of water to be treated.

According to another embodiment, the regulation is obtained by adjusting the thickness and density of the layer of porous or fibrous substance between the interface which is in contact with the water to be treated and the interface which is in contact with the volume of confined water.

For a correct functioning of the process of the invention, it is essential that, in the volume of oxygen-deficient confined water, the concentration of this gas be maintained at around one milligram per litre of water; in fact, above 1.5 milligrams per litre the denitrification is incomplete and production of nitrites occurs, which are particularly toxic substances; above 0.5 milligrams per litre of water there is generally a production of hydrogen sulphide, which is a gas which is toxic to the majority of aquatic organisms; this result is achieved by adjusting the thickness and density of the layer of porous or fibrous substance between the interface which is in contact with the water to be treated and the interface which is in contact with the volume of confined water, or by injecting a flow of water which passes in small quantities through the volume or volumes of confined water, the said flow being able to come, through a pipe, from the volume of water to be treated and returned by another pipe to this same volume of water to be treated.

The reactors (tanks) are connected in a cascade to form an installation in which the water enters at the first tank and leaves again at the last tank; when such an installation is used in open circuit, it is necessary to adjust the flow rate of the pumping equipment, and consequently the residence time of the water, so as to obtain pure water at the outlet from the last reactor; when the installation is connected, in close circuit,

to a reservoir containing the water to be treated, the flow rate of the pumping installation may vary within significant degrees without particularly effecting the functioning of the installation.

In a particular mode of implementing the method of the invention, the reactor is an aquarium, inside which the partition consists of sand or gravel, which is formed in a layer between two grids; one of the grids, situated at a small distance from the bottom of the aquarium, supports the layer of sand; the other grid, which is located above the first and which, for aesthetic reasons, is concealed underneath a thin layer of sand or gravel, serves to prevent the inhabitants of the aquarium, in particular certain fish, from scooping and clearing away some of the sand, which would have the harmful consequence of interfering with the functioning of the process and destroying the stratification of the layer of sand forming the partition and interrupting the confinement of the water occupying the space situated underneath the partition; it is the aquarium itself which serves as a reactor and the water which it contains is completely purified, without its being necessary to use any ancillary equipment other than that which is necessary for implementing the method of the invention.

The bacterial reactions, and particularly the denitrification reactions, release acid products which tend to acidify the environment and decrease the yield of the process. In order to avoid this drawback, the porous or fibrous material serving as a carrier for the bacteria will preferably be a carbonate substance, capable of neutralising the environment.

Advantageously a coarse calcareous sand such as Breton ameliorant (a sand consisting of the debris of calcareous algae and parts of skeletons of various marine invertebrates) or crushed coral, which are materials which, in addition to their neutralising power, offer many fixing sites for the various microorganisms used and particularly those which are responsible

for ammonisation, nitrification and denitrification, because of the great porosity of their constituents. In this particular case the partitioning of the reactor is achieved by depositing the Breton ameliorant or crushed coral on a grid, or again by filling the space produced between two grids. Excellent results have been obtained with a coarse sand of natural origin, consisting essentially of tests of benthic foraminifera, and formed by grains with a mean diameter varying between 2 and 3 mm. Following the neutralisation of the acid products, the carbonate substrates such as the Breton ameliorant and crushed coral dissolve slowly, releasing calcium ions which tend to alkalise the medium. Consequently the use of carbonate substrates will be avoided or the quantities used will be reduced, by mixing with a neutral product, when the method is used for purifying certain fresh water aquariums in which it is desired to maintain an acid pH. On the other hand, the release of calcium ions is very advantageous in the case of marine aquariums, since this phenomenon makes it possible to maintain the equilibrium of the CO₂ system, and consequently to maintain the buffer capability and the alkalinity of the pH of the sea water. These properties of the sea water are preserved, even when the aquarium contains many organisms capable of fixing large quantities of calcium carbonates, such as calcareous algae, scleractinaria, molluscs, tube worms, etc. In addition, under these conditions, the organisms in question can, without any limitation, derive from the water surrounding them the calcium necessary for constructing their skeletons. In extreme cases, the process of dissolution is sufficiently rapid to make periodic additions of carbonate substrate necessary.

The organic particles in suspension in the water to be treated are broken down by the bacteria which develop on their own surface, whilst those which come into contact with the porous or fibrous substance which serves as a carrier for the various microorganisms used are broken down and transformed into dissolved substances by the aerobic microorganisms which are to

be found in the oxygen-rich layer. One great originality of the process of the invention lies in the fact that the water to be treated does not pass through the main reaction space formed by the porous or fibrous material used. The exchanges of dissolved substances which take place between the water to be treated, the confined water and the various reaction zones situated in the main reaction space take place by diffusion, particularly through the interfaces which serve as boundaries between these different parts. The microorganisms responsible for ammonisation and nitrification occupy the oxygen-rich reaction zone, adjacent to the interface in contact with the water to be treated, transform the nitrogen compounds into nitrates and nitrites which diffuse in the direction of the oxygen-deficient zone, where they are reduced by the heterotrophic denitrifying microorganisms which are to be found there. It appears that a large proportion of the nitrites thus formed is reduced before having to be transformed into nitrates. These heterotrophic bacteria use, as a source of organic carbon, some of the carbon compounds present in the reaction medium, and come from the water to be treated. The molecular nitrogen, released by the reduction of the nitrate ions, diffuses in the direction of the oxygen-rich layer. It then passes into the water to be treated and finally reaches the atmosphere. Likewise, the calcium ions released in the main reaction space by the neutralisation of the acidic compounds produced by the various microorganisms used and particularly by the heterotrophic anaerobic microorganisms, diffuse in the direction of the water to be treated. It is flows of oxygen, nitrates, nitrogen, etc which pass across the different interfaces, according to the concentration gradients which structure the space in which the reactions are taking place. Because of this there is no risk of blockage. Another advantage, resulting from the fact that the exchanges of substances take place by diffusion, appears when the purification of the water is carried out in a closed circuit, comprising the reactor and a receptacle containing the water to be treated. In this case, in fact, the residence time of the

water inside the reactor has practically no influence on the functioning of the process, which means that it is unnecessary to regulate the flow rate of the pumping equipment.

In a variant of the process of the invention, the most superficial part of the layer which is in contact with the water to be treated is brightly illuminated and serves as a carrier for microalgae, which are thus associated with the aerobic bacteria. Under the effect of the light, the microalgae produce oxygen, which saturates the layer in which they are to be found.

The abundance of oxygen accelerates the breakdown of the organic materials by the aerobic microorganisms and in particular facilitates the work of the ammonifying and nitrifying bacteria, which has the effect of preventing the accumulation of toxic intermediate products constituted by the ammonium ions (and particularly the very toxic undissociated NH_3 fraction) and the nitrite ions. This is particularly important in the case of marine aquariums containing tropical organisms, in which the basic pH and high temperature mean that the undissociated proportion (NH_3) is very high. This variant, which has the effect of increasing the yield of the process, without changing its fundamental principles, does not depart from the scope of the invention.

In another variant of the process of the invention, the porous or fibrous material serving as a carrier for the microalgae and bacteria contains small burrowing detritivorous organisms such as those which live naturally in aquatic sediments. These small organisms participate in the elimination of the organic wastes and feed on those which come into contact with the partition. In addition, they disseminate organic particles in the body of the porous or fibrous material, through their dejections and their mechanical bioturbation action, which has the result of facilitating the breakdown of the organic particles which are incorporated in the oxygen-rich layer, and facilitating the

addition of carbon-containing substrate in contact with the heterotrophic denitrifying microorganisms to be found in the oxygen-deficient zone. As with the previous one, this variant, which has the effect of increasing the yield of the process without changing its fundamental principles, does not depart from the scope of the invention. It should be noted simply that the bioturbatory activity of these small organisms must be sufficiently moderate not to bring too much oxygen or too many organic particles into the oxygen-deficient layer which shelters the denitrifying microorganisms. In the contrary case, the functioning of the process would be seriously disturbed with the main consequence of a significant reduction in the yield of the denitrification reactions and a possible accumulation of toxic substances in the form of nitrite ions. This risk is easily avoided by choosing organisms of very small size, an operation which is within the capability of an expert and does not depart from the scope of the present invention.

According to an essential characteristic of the process of the invention, the different organisms, microorganisms and micro-algae used by the process of the invention are introduced into the reaction space, from strains selected for their effectiveness and cultivated for this purpose. It is however possible to use, as a reaction complex, an aquatic sediment taken directly from the natural environment and containing all its fauna, micro-fauna and micro-flora. It should be noted however that the degree of purification of the water and the reliability of the process of the invention depend both on the respective properties of the living or non-living constituents of the reaction complex and on compliance with the conditions for implementation which have been defined and described above.

The process therefore has absolutely decisive advantages, to which can be added the simplicity of its implementation.

The invention will again be illustrated, without in any way

being limited, by the following description given with reference to the accompanying drawings in which:

- Figure 1 shows a cross section illustrating diagrammatically an installation for implementing the process of the invention in a reactor (tank) through which the water to be treated passes and which has only a single horizontal partition;
- Figure 2 shows a cross section illustrating diagrammatically an installation for implementing the method of the invention inside an aquarium and according to which it is the aquarium itself which is used as the reactor;
- Figure 3 is a diagrammatic cross section similar to Figure 1, illustrating a variant of the installation shown in Figure 1, according to which several reactors (tanks) are connected in a cascade;
- Figure 4 shows a cross section illustrating diagrammatically an installation for the implementation of the process of the invention in a reactor (tank) through which the water to be treated passes and which has several vertical partitions.

Figure 1 shows diagrammatically an installation for implementing the process of the invention consisting of a reactor (tank), having a horizontal partition 1, formed by the porous or fibrous substance which serves as a carrier for the various active biological components used by the process of the invention.

The water to be treated, the level of which is represented diagrammatically by a horizontal line 9, circulates inside the reactor, in the space 2 situated above the partition 1. It is aerated and stirred by the injection of air through a diffuser 3. It enters the reactor through the orifice 4 and leaves it again through the orifice 5. The volume of confined, oxygen-deficient water occupies, in the bottom part of the reactor, the

space 6 situated below the partition 1. The interface (wall) 7 of the partition which is in contact with the water to be treated is brightly illuminated by means of a lamp or sun 8. The partition 1 has, in its body, several reaction zones: a zone supersaturated with oxygen 10 occupied by microalgae and aerobic microorganisms; an oxygen-rich zone 11 occupied by aerobic microorganisms; an oxygen-deficient zone 12 occupied by anaerobic microorganisms; an intermediate zone 13 in which aerobic microorganisms and anaerobic microorganisms are found. An installation of this type is suitable for the treatment, in closed circuit, of water contained in a storage tank. For treatment of water in open circuit, an installation of the type which is described in Figure 3 or Figure 4 will preferably be used.

Figure 2 shows diagrammatically a variant according to which the method is directly implemented inside an aquarium. The same signs designate the same components as in Figure 1. In this case, the partition 1 consists of sand or gravel, which is formed in a layer between two grids 14 and 15. The grid 15, situated at a short distance from the bottom of the aquarium, supports the layer of sediment. The grid 14, hidden for aesthetic reasons under a thin layer of sediment, prevents the inhabitants of the aquarium, and in particular certain fish, from scooping and clearing away some of the sediment, which would have the result of interfering with the functioning of the process by destroying the stratification of the sedimentary layer and interrupting the confinement of the water occupying the space 6 situated below the partition. In this example of installation, it is the aquarium itself which serves as the reactor. The water which it contains is completely purified, without its being necessary to use any ancillary equipment other than that which is necessary for implementing the method of the invention.

In the variant shown diagrammatically in Figure 3, the same

signs designate the same components as in Figure 1. The difference consists of the fact that several tanks are used in a cascade to form an installation in which the water enters at the first tank and leaves again at the last tank. The water to be treated enters the installation through the orifice 4 and leaves at 5. When such an installation is used in open circuit, it is necessary to adjust the flow rate of the pumping equipment, and consequently the residence time of the water, so as to obtain pure water at the outlet 5 from the last reactor. When the installation is connected, in closed circuit, to a reservoir containing the water to be purified, the flow rate of the pumping installation can vary within very large degrees without particularly effecting its functioning. In this system, since the water which arrives in the last tank (or tanks) no longer contains any organic material (or very little), it is no longer necessary to aerate and stir it. The last tank (or tanks) then fulfils the role of a decanting tank in which the mineral particles in suspension form a sediment.

Figure 4 shows diagrammatically an installation for implementing the process of the invention, consisting of a reactor (tank), having several vertical partitions. The same references designate the same components as in Figure 1. In addition to the active partitions consisting of the substance which serves as a carrier for the biological components used by the process of the invention, thin watertight partitions 16 have been shown, whose role is limited to channelling the water which circulates in the reactor. The main advantage of this mode of implementing the process lies in the fact that a large exchange area is available inside a small volume. The flow rate constraints vary depending on whether the installation is used in open circuit or closed circuit and are the same as those in the installation described in Figure 3.

Tables I, II and III show the changes in the pH values and concentrations of NH_4^+ , NO_2^- , NO_3^- and Ca^{++} ions in the water in

three closed-circuit aquariums, in which no change of water has been carried out for 10 months (Tables I and II) and 4 years (Table III) respectively.

TABLE I

MONTH	1	2	3	4	6	8	10	4 (years)
NH_4^+ (mg.l ⁻¹)	0.06	0.04	0.04	0.04	-	-	0.03	-
NO_2^- (mg.l ⁻¹)	0.08	0.08	0.08	0.08	-	-	0.08	-
NO_3^- (mg.l ⁻¹)	55.4	92.3	164	196	-	-	390	-
pH (units)	8.3	8.2	7.8	8.1	-	-	7.3	-

TABLE II

MONTH	1	2	3	4	6	8	10	4 (years)
NH_4^+ (mg.l ⁻¹)	0.23	0.17	0.23	0.11	-	-	0.11	-
NO_2^- (mg.l ⁻¹)	0.05	0.05	0.05	0.05	-	-	0.05	-
NO_3^- (mg.l ⁻¹)	41.9	62.9	137.5	163.2	-	-	281	-
pH (units)	8.3	8.1	7.8	7.9	-	-	6.5	-

TABLE III

MONTH	1	2	3	4	6	8	10	4 (years)
NH ₄ ⁺ (mg.l ⁻¹)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
NO ₂ ⁻ (mg.l ⁻¹)	0.002	0.001	0.002	0.004	0.008	0.002	0.001	0.001
NO ₃ ⁻ (mg.l ⁻¹)	0.350	0.230	0.007	0.012	0.006	0.008	0.006	0.013
Ca ⁺⁺ (mg.l ⁻¹)	480	480	460	500	490	480	480	520
pH (units)	8.22	8.26	8.30	8.25	8.20	8.22	8.25	8.24

Comparative tables of the values of the pH and of the NH₄⁺, NO₂⁻, NO₃⁻ and Ca⁺⁺ concentrations in the water in two closed-circuit marine aquariums, in which no change of water has been carried out for 10 months (Tables I and II) and 4 years (Table III) respectively.

TABLE I:

An aquarium equipped with a filter underneath active conchitic sand and containing only fish (the values in the table were calculated in accordance with the curves published in TERVERS, 1979, page 48).

TABLE II:

An aquarium equipped with vertical filtration on polyether foam and reverse draining on polyether foam and containing only fish

(the values in the table were calculated in accordance with the curves published in TERVERS, 1979, page 52).

TABLE III:

An aquarium functioning in accordance with the process of the invention and containing fish as well as many living corals (scleractinaria), diadem sea urchins and various other invertebrates (the pH measurements were carried out at approximately 5 pm). In fact, the pH of the aquarium water, which was used as an experiment, showed cyclic variations within a period of 24 hours, with on average a minimum value of 7.8 at 8 am and a maximum value of 8.25 at 5 pm).

In aquariums I and II, equipped with conventional biological filters, the pH, which was normal one month after the commissioning of the aquariums, fell gradually so as to attain, after ten months, the values of 7.3 (aquarium I) and 6.5 (aquarium II) respectively. The nitrate (NH_4^+) concentrations increased rapidly. After one month, they attained respectively the values of 54.4 mg.l^{-1} (aquarium I) and 41.9 mg.l^{-1} (aquarium II). After ten months, these concentrations had become very high: 390 mg.l^{-1} (aquarium I) and 281 mg.l^{-1} (aquarium II).

In the aquariums equipped according to the invention:

- the calcium ion concentration was high and stable (460 to 520 mg.l^{-1}),
- the pH remained normal and stable. The NH_4^+ and NO_2^- ion concentrations were 10 to 100 times lower than in aquariums I and II equipped with conventional filters,
- a comparison of the nitrate (NO_3^-) ion concentrations shows, in a particularly obvious way, the high degree of purification of the water, achieved through the process of the invention. In

fact, after the tenth month of operation, the nitrate concentration of the water in aquarium III was approximately 50,000 times lower than that of the water in aquariums I and II.

REFERENCES

1. Porous or fibrous partition
2. Volume of water to be treated
3. Air or oxygen diffuser
4. Inlet orifice
5. Outlet orifice
6. Confined water volume
7. Interface (two)
8. Lamp or sun
9. Water level
10. Zone supersaturated with oxygen
11. Oxygen-rich zone
12. Oxygen-deficient zone
13. Intermediate zone
14. Grid
15. Grid
16. Watertight partition



CLAIMS

1. Process for the biological purification of fresh or salt water containing solid and dissolved organic materials and dissolved mineral substances resulting from the decomposition of the said organic materials, and in particular of water in aquariums and aquaculture basins, using the action of aerobic and anaerobic microorganisms having the property of decomposing the organic materials and of neutralising the dissolved polluting materials, the water is treated inside one or more means serving as reactors, characterised by the fact that it uses one or more reactors (tanks) inside which the water is treated by DIFFUSION and the action of aerobic and anaerobic microorganisms; each reactor has, inside it, a main reaction space consisting of a porous or fibrous material (1) serving as a carrier for the various microorganisms used, which forms a thick partition (1) interposed between the volume of water to be treated (2) and one or more confined water volumes (6), the said main reaction space has means for maintaining concentration gradients of the various dissolved materials suitable for producing and maintaining the said diffusion.

2. Process according to Claim 1, characterised by the fact that:

a) the main reaction space is formed so that it comprises two interfaces (7) in contact, respectively, with the oxygen-rich water (2) to be treated and with a volume of confined oxygen-deficient water (6),

b) the main reaction space comprises, in its thickness, several adjacent reaction zones (schematically three zones 11, 12, 13): an oxygen-rich zone 11 adjacent to the interface in contact with the water to be treated, an oxygen-deficient reaction zone (12), adjacent to the interface in contact with the confined water, and an intermediate zone (13),



c) the oxygen-rich reaction zone (11) adjacent to the interface in contact with the water to be treated contains aerobic microorganisms which have the property of decomposing the organic materials, and in particular aerobic microorganisms which have the property of completely mineralising the nitrogen compounds (transformation into nitrates),

d) the oxygen-deficient reaction zone (12), adjacent to the interface in contact with the confined water, contains anaerobic microorganisms which have the property of neutralising the dissolved polluting materials (transformation into innocuous materials), and in particular heterotrophic anaerobic microorganisms having the property of completely reducing the nitrates (reduction of the nitrates to nitrites, and then of the nitrites to molecular nitrogen) and nitrites present in the water to be treated,

e) the intermediate zone (13) contains a mixture of aerobic and anaerobic microorganisms,

f) the confined water volume (6) is in darkness.

3. Process according to either one of Claims 1 or 2, characterised by the fact that the porous or fibrous material (1) serving as carrier for the aerobic and anaerobic microorganisms preferably consists of a carbonate material having a buffer effect and having the effect of correcting the pH of the water.

4. Process according to either one of Claims 1 or 2, characterised by the fact that the material (1) consists of crushed coral.

5. Process according to either one of Claims 1 or 2, characterised by the fact that the porous or fibrous material



(1) contains microalgae fixed in the thin surface layer (10) adjacent to the interface in contact with the water to be treated, and that this interface is brightly illuminated.

6. Process according to either one of Claims 1 or 2, characterised by the fact that small detritivorous burrowing organisms are introduced into the body of the porous or fibrous material (1).

7. Process according to either one of Claims 1 or 2, characterised by the fact that it is essential, for optimum functioning of the process according to the invention, that in the confined oxygen-deficient water volume (6) the concentration of this gas be maintained at about one milligram per litre of water by a regulating means.

8. Process according to Claim 7, characterised by the fact that the means for regulating the concentration of dissolved oxygen, which must be between 0.5 and 1 mg/l, may be a stream of water flowing through the said confined water volume(s) (6) in small amounts, the said stream being able to arrive through a pipe from the water volume (2) to be treated and to return through another pipe to this same water volume (2) to be treated.

9. Process according to Claim 7, characterised by the fact that the regulation is effected by adjusting the thickness and density of the layer of porous or fibrous material which is located between the interface in contact with the water to be treated and the interface in contact with the confined water volume.

10. Process according to either one of Claims 1 or 2, characterised by the fact that the main reaction space is used for creating concentration gradients structuring the interior of each reactor (gradients of oxygen, nitrogen, carbon dioxide, ammonium ions, nitrites, nitrates, calcium and other dissolved



materials).

11. Process according to either one of claims 1 or 2, characterised by the fact that it uses some of the organic materials in the water to be treated as a carbon-containing substrate, essential for the heterotrophic denitrifying microorganisms.

12. Process according to either one of Claims 1 or 2, characterised by the fact that means are used to prevent light from reaching the confined water volume (6) and illuminating the interface of the porous or fibrous material (1) in contact with the said confined water volume (6), and to prevent any release of oxygen through photosynthesis.

13. Device for carrying out the process according to either one of Claims 1 or 2, characterised by the fact that:

- it consists of one or more reactors (tanks) inside which the water is treated by DIFFUSION and the action of aerobic and anaerobic microorganisms,
- each reactor has, inside it, a main reaction space consisting of a porous or fibrous material (1) serving as a carrier for the various microorganisms used, and which forms a thick partition (1) interposed between the water volume (2) to be treated and one or more confined water volumes (6).

14. Device according to Claim 13, characterised by the fact that the partition wall (1) has, in its thickness, several reaction zones: a zone (10) supersaturated with oxygen and occupied by micro-algae and aerobic microorganisms; an oxygen-rich zone (11) occupied by aerobic microorganisms; an oxygen-deficient zone (12) occupied by anaerobic microorganisms; an intermediate zone (13) containing aerobic and anaerobic microorganisms.



15. Device according to either one of Claims 13 or 14, characterised by the fact that the inside of each reactor has one or more thick partitions (1).
16. Device according to either one of Claims 13 or 14, characterised by the fact that the inside of each reactor has one or more thick partitions (1) attached by their ends to the walls of the reactor.
17. Device according to either one of Claims 13 or 14, characterised by the thick partition wall(s) (1) being horizontal.
18. Device according to either one of Claims 13 or 14, characterised by the thick partition wall(s) (1) being vertical.
19. Device according to either one of Claims 13 or 14, characterised by the thick partition wall(s) (1) being inclined.
20. Device according to either one of Claims 13 or 14, characterised by the fact that the inside of each reactor comprises one or more thick partitions (1) which are not attached to the reactor walls and form one or more cavities containing the confined water (6).
21. Device according to either one of Claims 13 or 14, characterised by the fact that the porous or fibrous material forming the partition (1) and serving as a carrier for the various microorganisms used is preferably a carbonate material having a buffer effect and having the effect of correcting the pH of the water.
22. Device according to either one of Claims 13 or 14, characterised by the fact that the partition (1) consists of sand or gravel forming a layer between two grids (14, 15).



23. Device according to either one of Claims 13 to 14, characterised by the fact that the confined water volume(s) (6) may comprise a means for regulating the concentration of dissolved oxygen, which should be between 0.5 mg/l and 1 mg/l.