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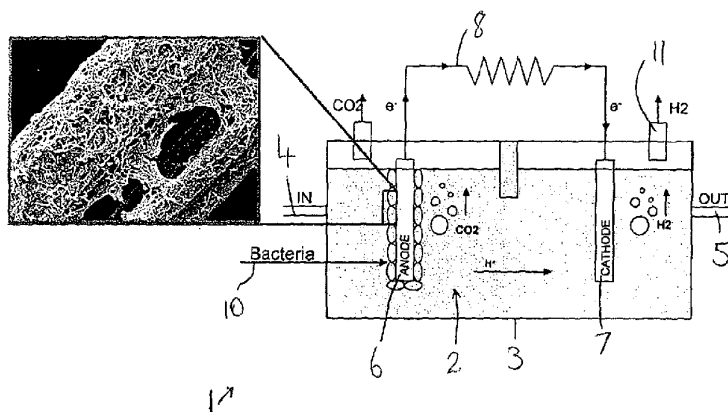


Fig. 1

(57) Abstract: The invention relates to an anode and a cathode for a microbial fuel cell, to a microbial fuel cell incorporating such an anode and/or cathode, a method of forming the anode or cathode and to a method of operating a microbial fuel cell. Embodiments disclosed include an anode for a microbial fuel cell comprising at least one electrode element adapted to be received within the microbial fuel cell, wherein the electrode element is of a polymer material having an electrically conductive material interspersed with the polymer material. Also disclosed is a cathode for a microbial fuel cell, wherein the cathode is of a polymer material having an electrically conductive material interspersed/integrated with the polymer material. Also disclosed are methods of manufacturing an anode for a microbial fuel cell, coating an electrode with a catalyst and a method of collecting nitrogen based compounds contained in waste water, such as nitrates, using a microbial fuel cell.

**AN ANODE AND CATHODE FOR A MICROBIAL FUEL CELL
AND A MICROBIAL FUEL CELL INCORPORATING
THE ANODE OR CATHODE**

5 This invention relates to an anode and a cathode for a microbial fuel cell. In particular, it relates to a microbial fuel cell anode and a microbial fuel cell cathode. It also relates to a microbial fuel cell incorporating such an anode and<Or cathode. It also relates to a method of forming the anode or cathode. Further, it relates to a method of operating a microbial fuel cell.

10 A microbial fuel cell is a device that converts chemical energy to electrical energy using microorganisms. The device can be used to treat waste water by breaking down the organic content therein and, as a by-product producing biogas and electricity. Biogas comprises gas produced by the break down of organic matter. In
15 a microbial fuel cell, the biogas is typically hydrogen and carbon dioxide. A typically microbial fuel cell includes an anode and a cathode extending into the waste water to be treated. The anode harbours microbes that consume the organic matter and electrons from the reaction are received by the anode. Protons (hydrogen ions) travel through the waste water to the cathode. There are two main
20 types of microbial fuel cell; those that include a proton transfer membrane and those that utilise the flow of the fluid to assist in transferring hydrogen ions/protons to the cathode.

25 WO 2009/131452 discloses a device comprising a first electrode compartment, the anode compartment, and a second electrode compartment, the cathode compartment, with a quantity of an anode fluid comprising an electrochemically oxidizable substrate and optional further compounds in the anode compartment, a quantity of a cathode fluid comprising an electrochemically reducible substrate and optional further compounds in the cathode compartment, and further an anode at
30 least partially in contact with the anode fluid in the anode compartment and a cathode at least partially in contact with the cathode fluid in the cathode compartment, wherein the anode and cathode are electrically connected and on the surface of the anode and the cathode a catalyst is present for respective catalysis of

the electrochemical conversion of the electrochemically oxidizable substrate via an electrochemical oxidation

Aspects and embodiments of the invention are set out in the appended claims.

According to a first aspect of the invention there is provided an anode for a microbial fuel cell according to claim 1.

This is advantageous because manufacture of the anode is cost effective and the electrically conductive material can be chosen to ensure that microorganisms such as bacteria can "stick" to the electrode elements when used in a microbial fuel cell. Thus, a non-conductive polymer can have an electrically conductive material dispersed therethrough which results in an easy to manufacture electrode that is conductive and provides an attractive harbour for microorganisms. It has been found that particles of the electrically conductive material can touch within the polymer matrix such that a reliably conductive anode can be formed.

Preferably the electrically conductive material is carbon black. This is advantageous as the polymer will typically have a resistivity of below 1×10^{-10} Ohm cm. By adding carbon black the resistivity will decrease significantly. For example, with 1 weight percent carbon black the resistivity is approximately 1×10^{-5} Ohm cm and with 2 weight percent, the resistivity can be of the order of 1×10^{-2} Ohm cm. Alternatively, the electrically conductive material may be carbon fibre, or silicon or a fullerene, such as Buckminster fullerene.

Preferably the electrically conductive material substantially comprises a powder, or a granular substance, that is interspersed with the polymer matrix. Preferably the powder or granular substance has a mean particle size in the range of 20 to 300 nm. It has been found that larger particles allow a lower viscosity to be achieved during moulding of the anode. Thus, preferably, the mean particle size is 200 nm to 300 nm.

Preferably the polymer material comprises polyethylene. Alternatively, other polymers can also be used, such as polystyrene, polyester, polyurethane or combinations of these.

5 Preferably the electrode element comprises between 1 % and 5% by weight of electrically conductive material to polymer material.

10 Preferably the anode comprises a plurality of electrode elements held within a cage. Thus, the anode may comprise a plurality, such as 10,000 to 100,000 electrode elements held within the cage. The cage is preferably of a non-metallic substance and is preferably non-conductive such as of a polymer material. The polymer may be the same as that used for the electrode elements. This is advantageous as the use of a plurality of electrode elements within a cage provides an "open scaffolding" for microorganisms with a large surface area. Further, this arrangement reduces the amount of flat surfaces upon which a sludge could form that hinders operation, which is a problem in prior designs. The cage provides means to hold the electrode elements together while allowing the electrolyte, such as waste water, to flow amongst the electrode elements.

20 Preferably the cage is arranged to urge the electrode elements together to improve electrical continuity through the electrode elements. The cage may include a lid which applies a compressive force to the plurality of electrode elements. This is advantageous as the lid is a convenient way of improving electrical conductivity and provides access to the cage.

25 Preferably the electrode elements comprise an external frame portion and an internal structure that extends within the frame portion between parts of the frame portion, wherein the external frame portion includes apertures such that, in use, electrolyte can pass over and/or microorganisms can gather on the external frame portion and the internal structure. This provides a large surface area upon which microorganisms can proliferate.

30 Preferably the external frame portion is generally tubular having apertures therein. The internal structure may comprise a plurality of struts that extend along

diameters of the tubular frame portion. Preferably the electrode elements comprise a plurality of spaced rings that form the external frame portion and the internal structure comprises struts to maintain the spaced ring configuration.

5 Preferably the surface of the or each electrode element is rough.

10 Preferably the conductive polymer material of the anode also includes a water treatment agent, at least at the surface, the water treatment agent adapted to treat pollutants in the water or do so on the application of an electric current to the anode. Preferably the water treatment agent is loaded onto the carbon black on the surface of the electrodes, such that it can bind to polluting elements, such as sulphur based compound, heavy metals or halogenated compounds. These compounds are normally present on part per million level. When the water treatment agents are fully saturated with the pollutant, the electrode may be
15 arranged to have an electric current run through it to liberate the concentrated pollutant which can then be isolated and removed in a controlled manner. The water treatment agent may be a porous medium based compound, such as activated carbon, an immobilized bio-catalyst, including enzymes, or a hetero- generous catalyst for removal of toxic compounds.

20 According to a second aspect of the invention, there is provided a method of manufacturing an anode for a microbial fuel cell according to claim 11.

25 Preferably, the electrically conductive material is carbon black. Preferably, the between 1 % and 5% by weight of electrically conductive material is provided to polymer material.

30 Preferably the step of dispersing the electrically conductive material comprises mixing the material in granular or powder form with molten polymer material.

Preferably the method includes a further step of adding the electrically conductive material to the surface of the anode. Preferably, this is achieved by brushing the anode with the electrically conductive material, or adding the electrically conductive material to the surface when the polymer is at an elevated temperature.

5 According to a non-claimed aspect of the invention we provide a cathode for a microbial fuel cell, wherein the cathode is of a polymer material having an electrically conductive material interspersed or integrated with the polymer material.

This is advantageous because the cathode can be easily moulded in to a variety of shapes to suit the particular application in a microbial fuel cell.

10 Preferably the cathode includes a coating of a catalytic material. Preferably the catalytic material is located substantially only at the surface of the cathode. This is advantageous as catalyst material is typically expensive and is not particularly active when located within the cathode rather than at or near its surface. Preferably, the catalytic material is selected to promote the recombination of the
15 electrons coming from the anode with a positive charged element released by the microbes at the anode, such as proton, to form neutral compounds, such as hydrogen bio-gas.

20 Preferably the catalytic material is Platinum.

Preferably the cathode is formed from a plurality of polymer beads that are fused together to form the cathode. This is advantageous as the use of polymer beads enables the shape and design of the cathode to be easily customised.

25 Preferably, the surface of the cathode is rough. In particular, the polymer material may have a textured surface rather than a smooth surface. In particular, the surface texture may be adapted to cause turbulence in the electrolyte when in use.

30 Preferably the electrically conductive material is carbon black. Alternatively, it may be carbon fibre, activated carbon or a fullerene, such as Buckminster fullerene. Preferably the electrically conductive material substantially comprises a powder, or is granular, that is interspersed with the polymer matrix. Preferably the polymer material comprises polyethylene. Preferably the electrode element comprises between 1 % and 5% by weight of electrically conductive material to

polymer material. Preferably the electrically conductive material comprises a powder or granular substance which has a mean particle size in the range of 20 to 300 nm. Preferably, the mean particle size is 200 nm to 300 nm.

5 Preferably the polymer material also includes a water treatment agent, at least at the surface, the water treatment agent adapted to be released on application of an electric current to the cathode. The water treatment agent may be a porous medium based compound, such as activated carbon, an immobilized bio-catalyst, including enzymes, or a hetero-generous catalyst for removal of toxic compounds.

10 According to a further non-claimed aspect of the invention we provide a method of manufacturing a cathode of a microbial fuel cell comprising the steps of:

providing a polymer material;

providing an electrically conductive material; and

15 dispersing the electrically conductive material within the polymer material and forming the cathode.

20 This is advantageous because the cathode can be moulded into any desired shape and includes an electrically conductive material dispersed within the polymer matrix. Further, the cathode is cost-effective to manufacture and has been found to be efficient in use.

25 Preferably, the electrically conductive material is carbon black. Preferably, between 1 % and 5% by weight of electrically conductive material is provided to polymer material.

Preferably before the cathode is formed, polymer and electrically conductive material is formed into beads that are then fused together to form the cathode.

30 Preferably the method includes the step of coating the surface of the cathode with a catalyst, such as Platinum. In particular, this step preferably comprises introducing the cathode to a Platinum solution. Preferably the Platinum solution is a Hexachloroplatinic(IV) Acid 6-hydrate solution reduced to form platinum nano-crystals on the carbon black exposed on the surface. Preferably the solution has a

concentration of below 3-4 weight percent of Platinum. It has been advantageously found that the Platinum is reliably deposited on the carbon black located at the surface of the cathode. This step is advantageous as only about 0.01 % of the electrically conductive material in the cathode by weight comprises Platinum (compared to about 5% by weight in prior art cathodes) while still providing its advantageous catalytic properties. This step of coating the surface of the cathode may form an aspect of the invention.

Thus, according to a further non-claimed aspect of the invention we provide a method of coating an electrode with a catalyst comprising the steps of:

providing an electrode comprising a polymer material having an electrically conductive material interspersed with the polymer material; and

introducing the cathode to a solution of a catalyst to cause the catalyst to adhere to at least the electrically conductive material.

Preferably the electrically conductive material is carbon black. Preferably, the catalyst is Platinum based catalyst, which may be, in particular, Platinum in a solution of Hexachloroplatinic(IV) Acid 6-hydrate. Alternatively, the catalyst may be an Iron based catalyst, a Molybdenum based catalyst or a Boron based catalyst.

According to a third aspect of the invention, there is provided a microbial fuel cell according to claim 14.

This is particularly advantageous for use in the milk industry or brewing industry where a large quantity of contaminated water (i.e. used as the electrolyte) is produced. The microbial fuel cell can be used to reduce the contamination level or organic content of the waste water before it is placed in the drain. Many water treatment companies charge depending degree of contamination of the water. Thus, the use of the microbial fuel cell will reduce the amount charged by a water treatment company for cleaning the water. As a by-product, biogas is typically produced, which can be collected and sold or used as a fuel. Further, the biomass produced in the cell can be used as a fertilizer. It is an object of the invention to provide a cell having electrodes with a lower resistivity for electricity production, to promote properties that facilitate the moulding of the anode, provide conditions

that stimulate proton removal from microbes, enhance microbial growth, encourage movement of organic and nitrogen compounds to migrate to the surface and facilitate microbial harvesting.

5 Preferably electrical contacts between the anode and cathode are adapted to be submersed in water. This is advantageous as submersing the electrical contacts substantially reduces the risk of explosion due to a connection between anode and cathode.

10 According to a fourth aspect of the invention, there is provided a method of treating water using the microbial fuel cell of the third aspect of the invention, according to claim 14.

15 Preferably the method includes the step of ensuring that waste water has a residence time at the anode surface for at least 24 hours. Preferably, this is achieved by setting the waste water flow rate appropriately or by providing an anode surface area sufficient to achieve the residence time with the flow rate through the cell.

20 According to a fifth aspect of the invention, there is provided a method of generating bio-gas using the microbial fuel cell of the third aspect of the invention, according to claim 17.

25 According to a sixth aspect of the invention, there is provided a method of collecting nitrogen based compounds contained in waste water, such as nitrates, using the microbial fuel cell of the third aspect of the invention, according to claim 18.

30 This is advantageous as the electrodes of carbon black dispersed within a polymer promote the liberation of dead microbial biomass from forming a bio-film on the surface of the electrode. The liberated bio-mass is directed to the surface where it can be easily collected. It has been found that the collected biomass has a nitrogen content of up to 15 weight percent nitrogen and the biomass can serve as fertilizer or as a high protein feed material.

There now follows by way of example only a detailed description of the present invention with reference to the accompanying drawings, in which:

5 **Figure 1** shows a diagram of an example of a microbial fuel cell;

Figure 2a shows a side view of an example of an electrode element;

10 **Figure 2b** shows a plan view of the electrode element of Figure 2a;

Figure 3 shows a side view of an embodiment of an anode;

Figure 4 shows a side view of an example of a cathode;

15 **Figure 5** shows a flow chart illustrating an example of manufacturing an anode or cathode; and

20 **Figure 6** shows a flow chart illustrating an example of coating an electrode with a catalyst.

25 Figure 1 shows a microbial fuel cell 1 for treating waste water 2, which comprises the electrolyte for the cell. The cell 1 includes an electrolytic vessel 3 having an inlet 4 and an outlet 5 for flowing the waste water 2 through the vessel 3. The cell 1 further comprises an anode 6 and a cathode 7 connected together through an external current flow path 8 and the electrolyte 2. The anode 6 is adapted, as will be described below, to harbour a microbial culture 10 (also shown in the blown-up photograph in figure 1) to treat the waste water 2. This microbial fuel cell 1 may be used by a milk producer or a brewer to treat the waste water that they produce which typically contains milk or brewing by-products. This organic material in the water can be reduced using the microbial fuel cell 1. Further, the microbial fuel cell will typically produce hydrogen 11 as a by-product of the treatment, which can be collected and sold as a bio-fuel.

5 The microbial fuel cell 1 receives waste water containing organic contaminants through inlet 4. The waste water is flowed slowly through the vessel 3 where the microbial culture on the anode 6 consumes the organic contaminants. In the process, electrons are received by the anode and transferred to the cathode 7 through the external current flow path 8. Hydrogen ions are carried with the flowing water 2 and are also attracted to the cathode 7, where they combine with the electrons to form hydrogen gas which is released at the cathode 7. The waste water 2 leaving the outlet 5 has been found to be cleaned by the cell 1.

10 The microbial culture is initially grown from a multi-culture source by keeping a representative waste-water solution stationary for about four days. This will enable the cultures to develop that are suited for microbial fuel cell activity under the nutritional conditions present within the waste-water. The microbial fuel cell as described herein can be used to generate bio-gas or to treat water or to generate
15 electricity or some or all of these.

The anode 6 comprises a plurality of electrode elements. Figures 2a and 2b show an example of an electrode element 20. The electrode element 20 comprises a generally tubular shape formed by a plurality of axially spaced rings 21, 22, 23. A
20 first ring 21 is connected to a second ring 22 by four connecting rods 24. The second ring 22 is connected to a third ring 23 by four further connecting rods 25. The electrode element 20 also includes cross members 26, 27 that extend between the rings and rods within the generally tubular shape. A first cross member 26 extends between the four connecting rods 24. A second cross member 27 extends
25 between the further connecting rods 25.

The electrode element 20 is of polyethylene having carbon black dispersed within the polymer matrix. In this example the electrode element 20 comprises 4% carbon black by weight. However, different ratios of carbon black to polymer could be
30 used. It has been found that between 1% and 5% carbon black by weight is appropriate and ensures that the resulting electrode element 20 has sufficient conductivity while not being too brittle. Further, carbon black has been found to be an advantageous material for the electrically conductive material as the bacteria of the microbial culture are able to effectively stick to the carbon black. Thus, the

electrode element 20 provides an open scaffolding to effectively harbour the culture.

5 It will be appreciated that different polymers could be used, such as a polyamide or polypropylene. The polymer must be able to accept a sufficient quantity of electrically conductive material into its polymer structure to be sufficiently conductive without being overly brittle. Also, different electrically conductive materials could be used other than carbon black, such as fragments of carbon fibre or fullerenes. The electrically conductive material must be sufficiently conductive to provide a current flow path when dispersed within a polymer and it is advantageous for the material to provide a surface to which the microbial culture can "stick". Carbon black has been found to provide such a surface.

10 The anode 6 comprises a plurality of electrode elements 20 held in electrical contact within a cage. The anode 6 is adapted to comprise around 50,000 electrode elements 20 held within the cage. Figure 3 shows a cage 30 holding thirty electrode elements 20 for clarity. The cage 30 comprises a substantially plate shaped structure having an open lattice as walls. The cage 30 is arranged to span the width of the vessel 3 to ensure that all of the waste water 2 entering the inlet 4 must flow through the cage 30 and thus between the electrode elements 20 on its way to the outlet 5. The cage 30 includes a lid 31 that slides within the cage 30. The lid 31 is arranged to apply pressure to the electrode elements 20 to improve electrical contact between the individual electrode elements 20 and therefore improve the current flow path throughout the anode 6.

25 Figure 5 shows a method of manufacturing the anode comprising step 50 of providing a polymer material, which in this example is polyethylene. Step 51 shows providing carbon black as the electrically conductive material of approximately 4% by weight of polymer material. Step 51 shows dispersing the carbon black through the polyethylene, while it is molten. Once cooled, a polymer-carbon black anode 6 can be moulded into shape. The anode 6 is electrically conductive due to the carbon black dispersed within the polymer.

Figure 5 may include the additional step of integrating a water treatment agent into the anode 6. The water treatment agent may be a porous medium based compound, including activated carbon, an immobilized bio-catalyst, including enzymes, or a hetero-generous catalyst for removal of toxic compounds, or a pH regulating compound. The water treatment agent may comprise a powder or granular substance that is dispersed in the polymer structure along with the carbon black. Alternatively, the water treatment substance may be applied to the surface of the anode 6 while the polymer is still partially molten. Further the water treatment agent may be applied to the anode 6 by placing the anode in a solution of the water treatment agent. The water treatment agent is selected to convert toxic material into non-toxic compounds. Alternatively, the water treatment agent may be selected to attach the toxic compound to the surface of the anode 6. When a substantial amount of toxic compounds have been accumulated on the anode's surface, a concentrated stream of the "disabled" toxic element can be removed physically or on application of a voltage to the anode. For example, a hydrogen sulphide pollutant can be captured by a water treatment agent of activated carbon. The captured hydrogen sulphide can then be released from the anode when a voltage of less than 10 V is applied and can then be extracted from the water.

Figure 4 shows the cathode 7 in the vessel 3 with the anode 6 not visible for clarity. The cathode 7 comprises a polymer material of polyethylene dispersed with carbon black to make it electrically conductive, as described above in relation to the anode 6. The cathode 7 comprises a substantially plate shaped member that is located between two further plates 40 and 41 placed horizontally or vertically with a confined space between them. Waste water is allowed to pass under plate 40 and forced to pass through the confined space between plate 40 and plate 41 therefore bringing it into close contact with the cathode. Thus the further plates 40 and 41 prevent the waste water 2 from bypassing the cathode 7 either in a horizontal or vertical direction. Also, the further plates 40, 41, when mounted in a vertical position allow for easy collection of hydrogen by guiding the gas to the surface where it can be collected at a particular point.

The cathode 7 is formed in a similar way to the anode 6 as illustrated in Figure 5. However, step 52 may comprise forming a plurality of beads of polymer dispersed

with carbon black, arranging these polymer-carbon beads into a plate arrangement and fusing the beads together using heat to form the cathode 7. The cathode 7 is formed with a rough surface.

5 The cathode 7 includes a Platinum catalyst on its surface. The Platinum catalyst is deposited on the carbon black that is exposed at the surface of the cathode 20. This is advantageous as previous cathodes for microbial fuel cells had Platinum dispersed through their whole volume, which is wasteful as the catalytic action occurs at the surface of the cathode 7.

10 Figure 6 shows a flow chart illustrating how the cathode is coated with the Platinum catalyst. Step 60 comprises providing an electrode, which in this example is the cathode 7 comprising a polymer dispersed with carbon black, as described above. Step 61 shows the cathode 7 being introduced to a weak Platinum solution of Hexachloroplatinic(IV) Acid 6-hydrate solution which is subsequently reduced to form platinum nano-crystals on the carbon black exposed on the surface. In this example, the solution has a concentration of below 3-4 weight percent of Platinum. It has been found that the Platinum adheres to the carbon black of the cathode 7 and does not penetrate much beyond the surface of the cathode 7. Thus, only a relatively small amount of Platinum is required to coat a cathode with an effective amount of catalyst.

20 In use, the waste-water is flowed through the device such that it has a contact time with the anode for at least 24 hours. For example, if the anode has a volume of 1 m³ the overall flow can be approximately 1 m³/day. The microbial culture breaks down the organic content of the waste water, which cleans the water, generates nitrogen rich biomass and releases biogas that can be collected.

25 Thus, the invention provides a cost effective microbial fuel cell based on electrically conductive polymer material chosen to ensure that microorganisms such as bacteria can "stick" to the electrode element when used in a microbial fuel cell. The electrodes and the cell of the invention have been found to allow easy moulding, stimulate proton removal from microbes, enhance microbial growth, encourage movement of organic and nitrogen compounds to migrate to surface and

5 facilitate microbial harvesting. The use of conductive polymer ensures a non-corrosive environment and safe connections in a water based system and for hydrogen bio-gas generation. The method facilitates the disinfection of water during or after treatment past the anode and cathode of the microbial fuel cell and extracting the water by the use of chemicals or the application of heat for pathogen removal.

10 In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

15 It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

CLAIMS

1. An anode for a microbial fuel cell, the anode comprising a cage and a plurality of electrode elements held within the cage, the cage adapted to be received within the microbial fuel cell, wherein the electrode elements comprise a polymer material having an electrically conductive material interspersed with the polymer material.
2. The anode according to claim 1, wherein the cage comprises a lid arranged to apply a compressive force to the plurality of electrode elements held in the cage.
3. An anode according to any one of the preceding claims, in which the electrically conductive material substantially comprises a powder, or a granular substance, that is interspersed with the polymer matrix.
4. An anode according to claim 3, in which the powder or granular substance has a mean particle size in the range of 20 to 300 nm.
5. An anode according to claim 3, in which the powder or granular substance has a mean particle size between 200 nm and 300 nm.
6. An anode according to any one of the preceding claims, in which the polymer material comprises polyethylene, polystyrene, polyester, polyurethane or combinations of these.
7. An anode according to any one of the preceding claims, in which the cage is of non-metallic material and may be an insulating material.
8. An anode according to any one of the preceding claims, in which each of the electrode elements comprises an external frame portion and an internal structure that extends within the frame portion between parts of the frame portion, wherein the external frame portion includes apertures such that, in use, electrolyte can pass over and/or microorganisms can gather on the external frame portion and the internal structure.

9. An anode according to claim 8, in which the external frame portion is generally tubular having apertures therein.

10. An anode according to claim 8 or claim 9, in which the internal structure comprises a plurality of struts that extend along diameters of the tubular frame portion.

11. A method of manufacturing an anode for a microbial fuel cell comprising the steps of:

providing a polymer material;
providing an electrically conductive material;
dispersing the electrically conductive material within the polymer material and forming a plurality of electrode elements; and
putting the plurality of electrode elements into a cage.

12. The method of claim 11, wherein the cage further comprises a lid, and the method further comprises the step of closing the lid to apply a compressive force to the plurality of electrode elements held in the cage.

13. A method according to claim 11 or 12, in which the method includes a further step of adding the electrically conductive material to the surface of the anode.

14. A microbial fuel cell comprising an anode and a cathode arranged in a vessel that contains a substrate, the anode comprising the anode of any one of claims 1 to 10 and the cathode comprising a polymer material having an electrically conductive material interspersed with the polymer material.

15. A method of treating water using the microbial fuel cell of claim 14, the method comprising:

providing the microbial fuel cell;
introducing waste water to the cell, the waste water having an organic content;
flowing the water to be treated past the anode and cathode of the microbial fuel cell; and
extracting water from the cell once the cell has reduced the organic content of the water.

16. A method according to claim 15 in which the method includes the step of ensuring that waste water has a residence time at the anode surface for at least 24 hours.

5 17. A method of generating bio-gas using the microbial fuel cell of claim 14, the method comprising:

providing the microbial fuel cell having a culture of microorganisms on the anode, the microorganisms being of a type that are able to consume organic content in waste water to be introduced to the cell;

10 introducing waste water to the cell, the waste water having an organic content; flowing the water to be treated past the anode and cathode of the microbial fuel cell; and

extracting bio-gas from cathode.

15 18. A method of collecting nitrogen based compounds contained in waste water, such as nitrates, using the microbial fuel cell of claim 14, the method comprising:

providing the microbial fuel cell having a culture of microorganisms on the anode, the microorganisms being of a type that are able to consume nitrogen contained in the waste water to be introduced to the cell and fix it within their body mass;

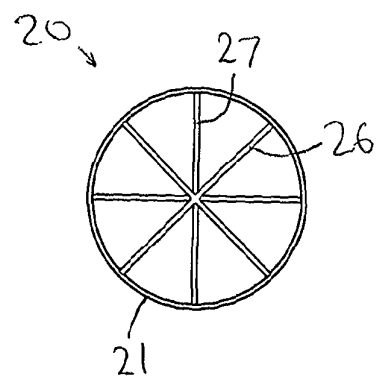
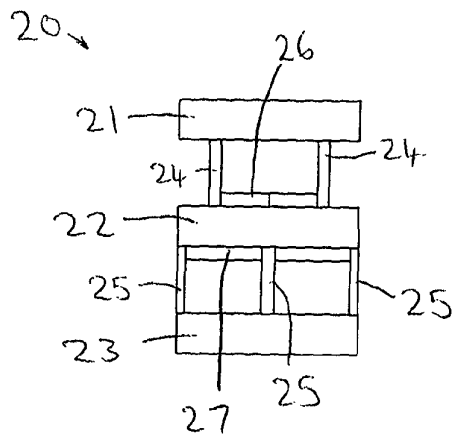
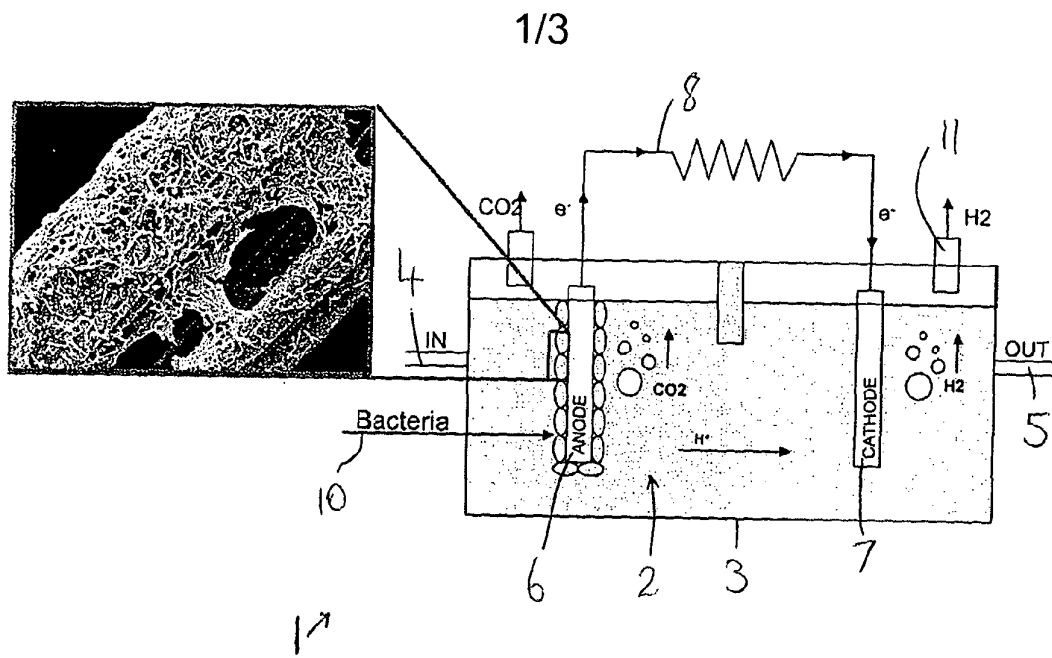
20 introducing waste water to the cell, the waste water having a nitrogen content, such as nitrates;

flowing the water to be treated past the anode and cathode of the microbial fuel cell; and

collecting the nitrogen compounds from the microbial fuel cell.

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19. A method of generating electricity using the microbial fuel cell of claim 14.



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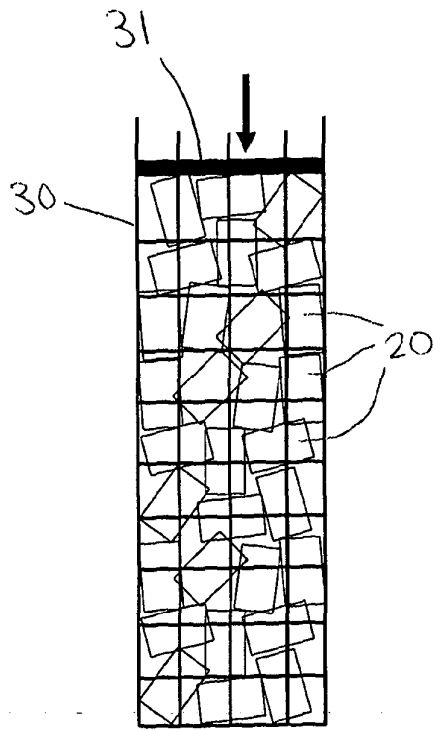


Fig. 3

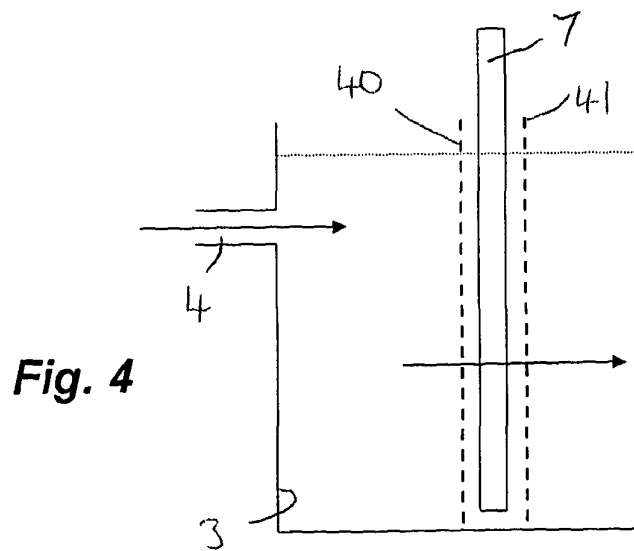
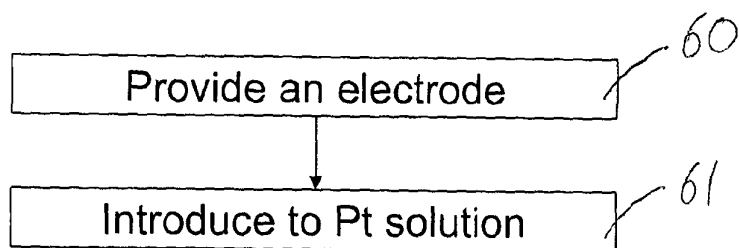
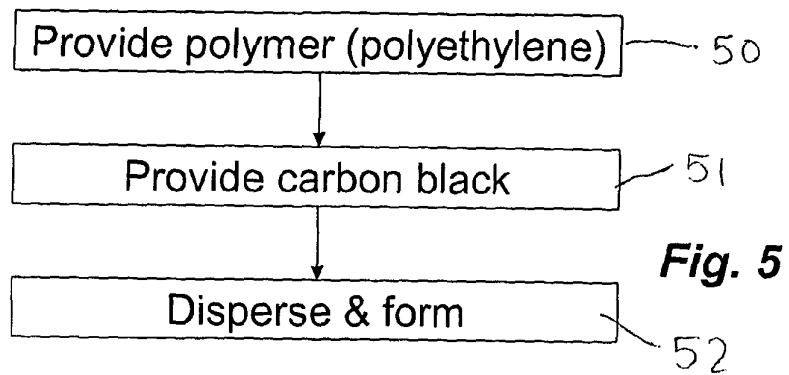


Fig. 4

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**Fig. 6**