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**GB-A- 936 470                    GB-A- 1 161 625**  
**GB-A- 1 270 426                US-A- 3 022 242**  
**US-A- 3 616 354                US-A- 4 171 254**  
**US-A- 4 318 787                US-A- 4 457 821**

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## Description

This invention relates to the corrosion protection of pipes, vessels and other corrodible substrates.

It is well known to protect substrates from corrosion by establishing a corrosion-protecting potential difference between the substrate and a counter-electrode. Preferably a DC power source is used to establish the desired potential difference between the substrate as cathode and an anode which is composed of a material which is resistant to corrosion, eg. platinum, graphite, or a conductive polymer. Reference may be made for example to U.S. Patents Nos. 3,515,654 (Bordalen), 4,502,929 (Stewart et al), 4,473,450 (Nayak et al), 4,319,854 (Marzocchi), 4,255,241 (Kroon), 4,267,029 (Massarsky), 3,868,313 (Gay), 3,798,142 (Evans), 3,391,072 (Pearson), 3,354,063 (Shutt), 3,022,242 (Anderson), 2,053,314 (Brown) and 1,842,541 (Cumberland), U.K. Patents No. 1,394,292 and 2,046,789A, Japanese Patents Nos. 35293/1973 and 48948/1978, and European Patent Publication No. 01479777.

The known corrosion systems suffer from serious disadvantages, in particular a failure to obtain sufficiently uniform current distribution on the substrate. This disadvantage can arise from the use of one or more discrete electrodes; or from the use of a distributed electrode, eg a platinum wire, whose radial resistance to the substrate is low, so that at high currents the current density on the anode decreases rapidly as the distance from the power source increases; and/or because the substrate is shielded (including those situations in which the substrate has a complex shape which results in one part of the substrate being shielded by another part of the substrate). The flexible elongate anodes disclosed in U.S. Patents Nos. 4,502,929 and 4,473,450, which comprise a low resistance core surrounded by a conductive polymer coating, are very useful in mitigating this disadvantage, but they cannot be used at the high current densities which are required in certain situations, for example the protection of structures which have no protective coating thereon. Another disadvantage is the relatively short life of anodes (including the electrical connections thereto), especially when exposed to environments which are highly corrosive or which contain oily contaminants (and in the case of platinum anodes, when exposed to fresh potable water), and the difficulty and expense of repairing or replacing the anodes when this becomes necessary.

We have now discovered that these disadvantages can be mitigated or overcome by means of a barrier which lies between the substrate and the counter-electrode, which is spaced apart from the

substrate and the counter-electrode, and which directs the flow of ions between the substrate and the counter-electrode, and thus provides an improved current distribution on the substrate, and/or enables the counter-electrode to be more easily maintained or replaced, and/or reduces the rate at which the current density on an elongate electrode changes with the distance from the power source, and/or provides a controlled environment around the electrode to improve its efficiency, eg. by reducing contamination or by making it possible to surround the counter-electrode with an electrolyte which is different from the electrolyte which contacts the substrate.

In one aspect, the present invention provides an assembly for cathodically protecting an electrically conductive substrate from corrosion, the assembly comprising:

- (1) an electrically conductive substrate which is liable to corrosion;
- (2) an elongate distributed anode which has a shape corresponding generally to the shape of the substrate and
- (3) a layer which (i) lies between the substrate and the anode (ii) is spaced apart from the substrate and the anode and (iii) is in the form of a tube which surrounds the anode but which when the anode and the substrate are electrically connected to opposite poles of a DC Source, and a circuit is completed by means of an electrolyte between the anode and the substrate, allow electrical current to flow between the anode and the substrate, characterised in that

(a) the said layer is a barrier comprising a plurality of sections that are ion permeable, such that when the anode and the substrate are electrically connected to opposite poles of a DC source the distribution and/or the size of the ion permeable sections restricts the flow of electrical current between the substrate and the anode, compared to the current flow that would pass in the absence of the barrier, such that the resistance between the substrate and the anode is Q times the resistance between them in the absence of the barrier, where Q is at least 1.5, preferably at least 10, particularly at least 100, and

(b) the assembly also comprises a pump for pumping liquid electrolyte down the tube and through the ion permeable sections towards the substrate.

In another aspect, the present invention provides a method of cathodically protecting an electrically conductive substrate from corrosion by a liquid electrolyte which contacts it, which method comprises establishing a potential difference between the substrate as cathode and an elongate

distributed anode such that current flows between the substrate and the anode along current paths which pass through ion permeable sections of a barrier which (i) lies between the substrate and the anode, and (ii) is spaced apart from the substrate and the anode, and (iii) is in the form of a tube which surrounds the anode and has a plurality of ion-permeable sections therein, and in which method a pump drives an electrolyte down the tube and through the ion permeable sections towards the substrate.

The barrier which is used in the present invention modifies the way in which current flows between the substrate and the anode so as to produce one or more of the desirable results noted above. In general, this will result in the resistance between the substrate and the anode being substantially higher than it would be in the absence of the barrier, preferably by a factor of at least 10, for example at least 100, or even more, balancing the resulting advantages against the disadvantage of the higher voltages required as the resistance increases.

The barrier preferably comprises a plurality of ion-permeable sections. Preferred ion-permeable sections include simple apertures, for example a hole in the wall of a tube, or an opening at the end of a tube. Ion-permeable sections which are composed of an ion-permeable material, eg. a glass frit, can also be used, especially when it is desired to have the anode contacted by an electrolyte which is different from that which contacts the substrate. The size and/or the spacing of the ion-permeable sections can be uniform or non-uniform, depending upon the desired current distribution on the substrate. The ion-permeable sections are preferably of fixed dimensions. The distance between adjacent ion-permeable sections is preferably less than 10 times, particularly less than 4 times, the distance between the ion-permeable sections and the substrate. An important factor in determining the size of the apertures can be the need to ensure that anodic reaction products, eg. gaseous chlorine, do not block the apertures. Unless the conditions of operation are such that anodic reaction products remain dissolved in the electrolyte or can be easily vented, care must be taken to prevent harmful build-up of such reaction products between the anode and the barrier. In some case positive benefit can be derived from such reaction products, eg. to lessen fouling of marine structures. To assist in the dispersion of such reaction products, hydrostatic pressure is used to drive the electrolyte through the ion-permeable section(s) towards the substrate. Such hydrostatic pressure, which is provided by a pump, can have the alternative and/or additional advantages of (1) reducing the danger that the ion-permeable sections will be blocked by

contaminants present in the electrolyte between the barrier and the substrate, for example oily contaminants in the water layer at the bottom of an oil storage tank, and/or (2) making it possible, when it is desired to surround the anode with an electrolyte which is different from the electrolyte which contacts the substrate (eg. when protecting a potable water tank with a platinum anode), to prevent substantial contamination of the anode electrolyte by the substrate electrolyte with minimal contamination of the substrate electrolyte by the anode electrolyte.

The barrier must not be electronically connected to the substrate or the anode, and is preferably composed of (including coated by) an electrically insulating material, eg. a plastic. Preferred barriers are in the form of a tube (which may be of round or other cross section) or a plurality of tubes which are joined together to form a branched structure. In such a branched structure, the branch tubes are preferably of smaller cross-section than the main tube, for example so that the total cross-sectional area of the branch tubes is no greater than the cross-sectional area of the main tube. The tube or tubes can be heated by an internal or external heater to reduce the viscosity of the electrolyte therein (including to prevent it from freezing) and/or to reduce its resistivity. The tube or tubes can be arranged as a continuous loop, so that electrolyte circulates through them, or can simply terminate in an open end (ie. an ion-permeable section) or a closed end.

In a particularly preferred embodiment, the tube (or at least one of the tubes where a plurality of tubes are joined together) surrounds an elongate anode, for example one whose length is at least 100 times, preferably at least 1000 times, its smallest dimension, typically a metal wire, especially a platinum or platinum-coated wire, having for example a diameter of at least 0.01 inch (0.025 cm), preferably 0.02 to 0.3 inch (0.05 to 0.075 cm). The internal diameter of the tube containing the wire anode is preferably P times the diameter of the wire, where P is 2 to 100, eg. 5 to 30, for example a diameter of 0.125 to 0.6 inch (0.36 to 1.5 cm). The tube containing the wire anode comprises ion-permeable sections, or there are branch tubes comprising ion-permeable sections attached thereto, or both. The branch tubes can comprise perforations and/or can have an open end, which may be fitted with a nozzle. In this way, it is possible to obtain a much more uniform current density on the anode, and hence also on the substrate, than in the absence of the barrier. This desirable result is achieved because the resistance between the substrate and the elongate anode is much greater than it would be in the absence of the tube or tubes, preferably by a factor of at least 10, for example at

least 100 or even higher. This is especially valuable when it is desirable to provide a high current from a distributed anode. Under these circumstances, it is not satisfactory to use an anode comprising a metal core and a conductive polymer jacket, because such anodes cannot support the high current densities required. Nor is it satisfactory to use a platinum wire anode (or the like); such anodes will support very high current densities, but at the currents needed in such circumstances, the current density on the anode decreases rapidly as the distance from the power source increases, as demonstrated for example in Example 1 below.

Any appropriate DC power source can be used in the present invention. The voltage of the power source is preferably less than 100 volts, particularly less than 50 volts, with the system being designed with this preference in mind.

When there is a net transfer of electrolyte through the ion-permeable section(s) of the barrier, electrolyte must be supplied to the anode, and this can be done by recycling electrolyte from the vicinity of the substrate and/or by supplying fresh electrolyte. When build-up of electrolyte in the vicinity of the substrate must be avoided, eg. in the bottom of an oil storage tank, means must be provided for removing excess electrolyte; the excess electrolyte can be recycled to the anode, if desired or necessary after filtering or otherwise treating it to remove harmful contaminants.

Preferred uses for the present invention include the protection of city water tanks, ballast tanks in ships, oil rigs, cooling tanks for power stations, water tanks for secondary recovery in oil wells, oil storage tanks, heat exchangers, condensers, heater treaters, and buried pipes, in particular pipes buried below the permafrost line, for example oil pipes in frozen tundra.

Referring now to the drawings, Figure 1 shows a DC power source 1 which is connected to an anode 2 and a corrodible substrate 3 which is a cathode. Anode 2 and substrate 3 are separated by a barrier 4 which comprises ion-permeable sections 45, and are connected by electrolyte 5 through sections 45. A positive hydrostatic pressure is maintained from the interior of the barrier 4 across the ion-permeable sections 45 by means of pump 6.

Figure 1 is a diagrammatic side view which shows the corrodible substrate 3 within a vessel 7 containing the electrolyte 5. The anode 2 is an elongate anode, and the barrier 4 is a perforated tube containing the anode.

Figure 2 shows in diagrammatic plan view an alternative way of protecting a vessel 3. Tube 44 surround the vessel and contains elongate anode 2. Branch tubes 42 communicate with tube 44, pass through the wall of the vessel, and terminate in

open ends or nozzles 45 which can point in one or more desired directions.

Figure 3 shows a tube with perforations therein through which ion-containing electrolyte can emerge; the perforations shown are uniformly spaced and of uniform size, but they could be of different sizes and separations in order to provide desired current distribution. Figure 4 shows a tube composed of an ion-conducting membrane through which ions can pass, but non-ionic material cannot. Figure 5 shows a perforated tube which is covered by an ion-conducting membrane. Figure 6 shows a part of a perforated tube in which each perforation is covered by an ion-conducting membrane. Figure 7 shows an open-ended tube through the open end of which ion-containing electrolyte can emerge. Figure 8 shows an open-ended tube whose open end is covered by a porous plug. Figure 9 shows a tube having a plurality of branch nozzles mounted thereon.

The invention is illustrated in the following Example.

#### EXAMPLE 1

In this Example, procedures (A) and (B) are comparative examples and procedure (C) is an example of the invention.

(A) A plastic trough about 18 feet (5.5m) long and of semi-circular cross-section, diameter 4 inch (10.2cm), was connected by means of a drain to a plastic tank containing a submersible pump. The trough, the tank and the drain were filled with aqueous potassium chloride electrolyte of resistivity 20.5 ohm.cm. A mild steel rod about 18 feet (5.5m) long and 0.5 inch (1.25cm) in diameter was placed in the bottom of the trough. A plastic tube about 18 feet (5.5m) long, 0.375 inch (0.95cm) in inner diameter and 0.5 inch (1.25cm) in outer diameter was secured to the wall of the trough, parallel to the mild steel rod and spaced apart from it. The plastic tube comprised holes 0.010 inch (0.025 cm) in diameter every 3.94 inch (10 cm) along a straight line, and the tube was secured to the trough so that the holes were 0.75 to 1 inch (1.9-2.5cm) from the mild steel rod. One end of the tube was connected to the submersible pump in the tank and the other end was sealed. The pump was used to pump electrolyte through the tube. Excess electrolyte returned from the trough to the tank through the drain. A saturated calomel reference electrode (SCE) was placed in the trough in a number of different positions so that the potential of different parts of the rod could be measured. The corrosion potential of the rod was measured to be between 0.626 and 0.699V, an average of 0.655V.

(B) The apparatus described in (A) was modified by securing a platinum wire anode 0.010 inch (0.025 cm) in diameter and about 18 foot (5.49m) long to the surface of the plastic tube so that the anode was 0.75 to 1 inch (1.9 to 2.5 cm) from the rod. The rod and one end of the anode were connected to a DC power source of sufficient voltage to maintain a current of 0.5 amp. The absolute potential of the rod (i.e. the potential measured by the SCE minus the corrosion potential) was found to be 0.62V at the end which is adjacent the end of the anode connected to the power source, and to decrease to 0.05V at the other end, a total difference of 0.57V.

(C) The apparatus described in (B) was modified by placing the anode inside the plastic tube. The power source was adjusted to provide a current of 0.5 amp, and the pump was adjusted to provide a flow rate which ensured that the holes in the tube were not plugged by the gaseous products evolved at the anode (i.e. chlorine and oxygen). The absolute potential of the rod was found to be between 0.40 and 0.55V, i.e. a total difference of 0.15V.

#### Claims

1. An assembly for cathodically protecting an electrically conductive substrate from corrosion, the assembly comprising;
  - (1) an electrically conductive substrate which is liable to corrosion;
  - (2) an elongate distributed anode which has a shape corresponding generally to the shape of the substrate and
  - (3) a layer which (i) lies between the substrate and the anode (ii) is spaced apart from the substrate and the anode and (iii) is in the form of a tube which surrounds the anode but which when the anode and the substrate are electrically connected to opposite poles of a DC Source, and a circuit is completed by means of an electrolyte between the anode and the substrate, allows electrical current to flow between the anode and the substrate, characterised in that
    - (a) the said layer is a barrier comprising a plurality of sections that are ion permeable, such that when the anode and the substrate are electrically connected to opposite poles of a DC source the distribution and/or the size of the ion permeable sections restricts the flow of electrical current between the substrate and the anode, compared to the current flow that would pass in the absence of the barrier, such that the resistance be-

tween the substrate and the anode is Q times the resistance between them in the absence of the barrier, where Q is at least 1.5, preferably at least 10, particularly at least 100, and

(b) the assembly also comprises a pump for pumping liquid electrolyte down the tube and through the ion permeable sections towards the substrate.

2. An assembly according to claim 1 wherein the distribution and/or the size of the ion permeable sections is non-uniform along the tube.
3. An assembly according to claim 1 or 2 wherein the length of the anode is at least 100 times, preferably at least 1000 times, its smallest dimension, and the barrier is in the form of a tube which is composed of an insulating material, and which has apertures in the walls thereof.
4. An assembly according to claim 1,2 or 3 wherein the barrier further comprises a plurality of branch tubes, each of the branch tubes communicating with the tube and having at least one aperture therein.
5. An assembly according to any of the preceding claims wherein the anode is a metal wire having a diameter of 0.05 to 0.75 cm. and the internal diameter of the tube is P times the diameter of the wire, where P is 2 to 100, preferably 5 to 30.
6. An assembly according to any of the preceding claims wherein the anode has a platinum surface.
7. A method of cathodically protecting an electrically conductive substrate from corrosion by a liquid electrolyte which contacts it, which method comprises establishing a potential difference between the substrate as cathode and an elongate distributed anode such that current flows between the substrate and the anode along current paths which pass through ion permeable sections of a barrier which (i) lies between the substrate and the anode, and (ii) is spaced apart from the substrate and the anode, and (iii) is in the form of a tube which surrounds the anode and has a plurality of ion-permeable sections therein, and in which method a pump drives an electrolyte down the tube and through the ion permeable sections towards the substrate.

#### Patentansprüche

1. Anordnung zum kathodischen Schutz eines elektrisch leitfähigen Substrats gegen Korrosion, wobei die Anordnung folgendes aufweist:
  - (1) ein elektrisch leitfähiges Substrat, das korrosionsanfällig ist; 5
  - (2) eine langgestreckte, verteilte Anode, die eine Form hat, die im allgemeinen der Form des Substrats entspricht; und 10
  - (3) eine Schicht, die (i) zwischen dem Substrat und der Anode liegt, (ii) von dem Substrat und der Anode beabstandet ist und (iii) die Form eines Rohres aufweist, das die Anode umgibt, das aber, wenn die Anode und das Substrat mit entgegengesetzten Polen einer Gleichstromquelle elektrisch verbunden sind und durch einen Elektrolyten zwischen der Anode und dem Substrat ein Schaltkreis geschlossen ist, es ermöglicht, daß ein elektrischer Strom zwischen der Anode und dem Substrat fließt, 15  
dadurch gekennzeichnet, daß
    - (a) die genannte Schicht eine Sperrschicht ist, die eine Vielzahl von Bereichen aufweist, die ionendurchlässig sind, so daß dann, wenn die Anode und das Substrat mit entgegengesetzten Polen einer Gleichstromquelle elektrisch verbunden sind, die Verteilung und/oder die Größe der ionendurchlässigen Bereiche das Fließen von elektrischem Strom zwischen dem Substrat und der Anode begrenzt, verglichen mit dem Strom, der bei Abwesenheit der Sperrschicht fließen würde, so daß der Widerstand zwischen dem Substrat und der Anode das Q-fache des Widerstandes zwischen diesen bei Abwesenheit der Sperrschicht ist, wobei Q wenigstens 1,5, vorzugsweise wenigstens 10, insbesondere wenigstens 100 ist, und 20
    - (b) die Anordnung ferner eine Pumpe aufweist, um flüssigen Elektrolyten durch das Rohr und durch die ionendurchlässigen Bereiche in Richtung auf das Substrat zu pumpen. 25
2. Anordnung nach Anspruch 1, wobei die Verteilung und/oder die Größe der ionendurchlässigen Bereiche längs des Rohres ungleichmäßig ist. 30
3. Anordnung nach Anspruch 1 oder 2, wobei die Länge der Anode wenigstens das 100-fache, vorzugsweise wenigstens das 1000-fache, ihrer kleinsten Dimension ist, und die Sperrschicht in Form eines Rohres vorliegt, das aus einem Isoliermaterial besteht und in seinen Wandun-

gen Öffnungen aufweist.

4. Anordnung nach Anspruch 1, 2 oder 3, wobei die Sperrschicht ferner eine Vielzahl von Abzweigrohren aufweist, wobei jedes der Abzweigrohre mit dem Rohr in Verbindung steht und wenigstens eine Öffnung darin hat. 35
5. Anordnung nach einem der vorhergehenden Ansprüche, wobei die Anode ein Metalldraht mit einem Durchmesser von 0,05 cm bis 0,75 cm ist und der Innendurchmesser des Rohres das P-fache des Durchmessers des Drahtes ist, wobei P einen Wert von 2 bis 100, vorzugsweise von 5 bis 30 hat. 40
6. Anordnung nach einem der vorhergehenden Ansprüche, wobei die Anode eine Platinoberfläche hat. 45
7. Verfahren zum kathodischen Schützen eines elektrisch leitfähigen Substrats gegen Korrosion durch einen flüssigen Elektrolyten, der mit ihm in Berührung steht, wobei das Verfahren folgendes aufweist: Ausbilden einer Potentialdifferenz zwischen dem Substrat als Kathode und einer langgestreckten, verteilten Anode, so daß ein Strom zwischen dem Substrat und der Anode längs Strompfaden fließt, die durch ionendurchlässige Bereiche einer Sperrschicht verlaufen, die (i) zwischen dem Substrat und der Anode liegt und (ii) von dem Substrat und der Anode beabstandet ist und (iii) in Form eines Rohres vorliegt, das die Anode umgibt und eine Vielzahl von ionendurchlässigen Bereichen darin hat, und wobei bei dem Verfahren eine Pumpe einen Elektrolyten durch das Rohr und durch die ionendurchlässigen Bereiche in Richtung auf das Substrat fördert. 50

#### Revendications

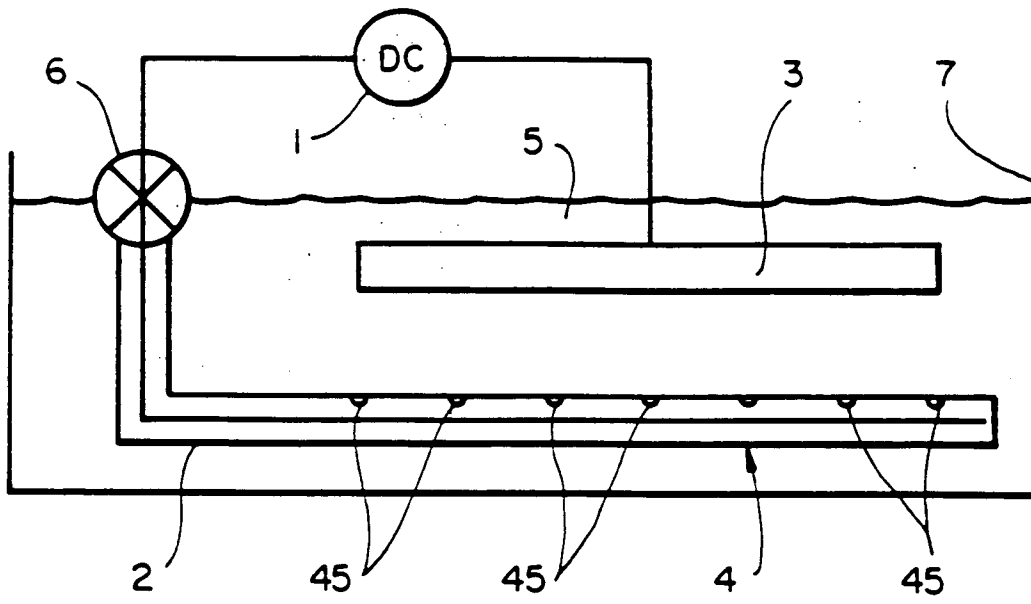
1. Ensemble pour la protection cathodique contre la corrosion d'un substrat électriquement conducteur, l'ensemble comportant :
  - (1) un substrat électriquement conducteur qui est sujet à une corrosion ;
  - (2) une anode allongée répartie qui présente une forme correspondant de façon générale à la forme du substrat, et
  - (3) une couche qui (i) s'étend entre le substrat et l'anode, (ii) est espacée du substrat et de l'anode et (iii) se présente sous la forme d'un tube qui entoure l'anode mais qui, lorsque l'anode et le substrat sont connectés électriquement à des pôles opposés d'une source de courant continu et qu'un circuit est fermé au moyen d'un élec-

trolyte entre l'anode et le substrat, permet à un courant électrique de circuler entre l'anode et le substrat, caractérisé en ce que

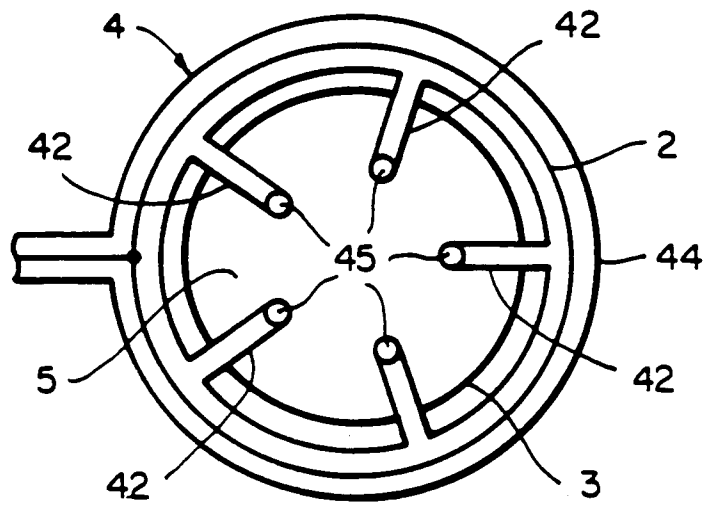
- (a) ladite couche est une barrière comprenant plusieurs sections qui sont perméables à des ions, de manière que, lorsque l'anode et le substrat sont connectés électriquement à des pôles opposés d'une source de courant continu, la distribution et/ou la dimension des sections perméables aux ions restreignent la circulation de courant électrique entre le substrat et l'anode en comparaison avec la circulation de courant qui passerait en l'absence de la barrière, de manière que la résistance entre le substrat et l'anode soit Q fois la résistance entre eux en l'absence de la barrière, où Q est d'au moins 1,5, avantageusement d'au moins 10, en particulier d'au moins 100, et
- (b) l'ensemble comporte aussi une pompe destinée à faire circuler par pompage un électrolyte liquide dans le tube et à travers les sections perméables aux ions vers le substrat.

2. Ensemble selon la revendication 1, dans lequel la distribution et/ou la dimension des sections perméables aux ions ne sont pas uniformes le long du tube.
3. Ensemble selon la revendication 1 ou 2, dans lequel la longueur de l'anode est d'au moins 100 fois, avantageusement d'au moins 1000 fois, sa plus petite dimension, et la barrière se présente sous la forme d'un tube qui est composé d'une matière isolante et dont la paroi présente des ouvertures.
4. Ensemble selon la revendication 1, 2 ou 3, dans lequel la barrière comprend en outre plusieurs tubes de dérivation, chacun des tubes de dérivation communiquant avec le tube et ayant au moins une ouverture.
5. Ensemble selon l'une quelconque des revendications précédentes, dans lequel l'anode est un fil métallique ayant un diamètre de 0,05 à 0,75 cm, et le diamètre intérieur du tube est P fois le diamètre du fil, où P est de 2 à 100, avantageusement 5 à 30.
6. Ensemble selon l'une quelconque des revendications précédentes, dans lequel l'anode présente une surface de platine.
7. Procédé pour la protection cathodique d'un

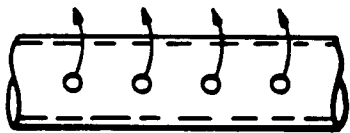
substrat électriquement conducteur contre une corrosion par un électrolyte liquide qui est en contact avec lui, lequel procédé consiste à établir une différence de potentiel entre le substrat en tant que cathode et une anode répartie allongée de manière qu'un courant circule entre le substrat et l'anode suivant des trajets de courant qui passent à travers des sections perméables à des ions d'une barrière qui (i) s'étend entre le substrat et l'anode, (ii) est espacée du substrat et de l'anode, et (iii) se présente sous la forme d'un tube qui entoure l'anode et comprend plusieurs sections perméables à des ions, procédé dans lequel une pompe entraîne un électrolyte le long du tube et à travers les sections perméables aux ions vers le substrat.



**FIG\_1**



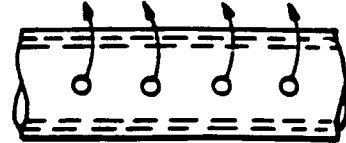
**FIG\_2**



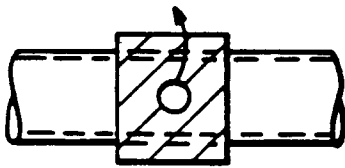
**FIG\_3**



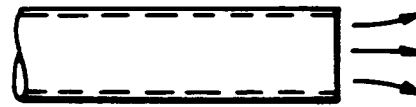
**FIG\_4**



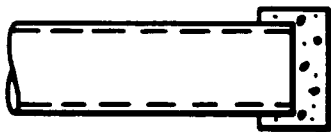
**FIG\_5**



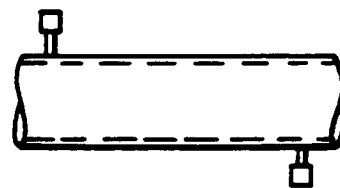
**FIG\_6**



**FIG\_7**



**FIG\_8**



**FIG\_9**