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(71) Applicant: **Hitachi, Ltd.**
Chiyoda-ku
Tokyo 100-8280 (JP)

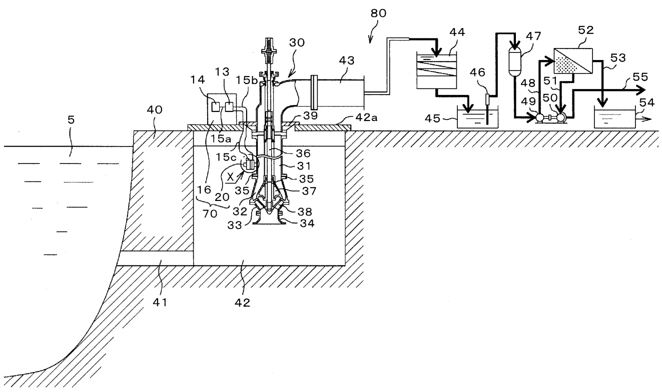
(72) Inventors:
- **KOBAYASHI Reo**
  Tokyo 100-8280 (JP)
- **OHASHI Kenya**
  Tokyo 100-8280 (JP)
- **ITOH Masahiro**
  Tokyo 100-8280 (JP)
- **CHIBA Yoshimasa**
  Tokyo 100-8280 (JP)
- **MIYACHI Takayoshi**
  Tokyo 100-8280 (JP)

(74) Representative: **Beetz & Partner mbB**
Patentanwälte
Steinsdorfstraße 10
80538 München (DE)

(54) ELECTROLYTIC PROTECTION SYSTEM AND PUMP DEVICE PROVIDED WITH SAME

(57) The life of a sacrificial anode for use in a pump device, such as a seawater pump, is extended, thus extending the life of a corrosion protection system of the seawater pump device. A pump device 30 includes a corrosion system 70 including: a measurement unit 20 located at a portion of a column pipe 33 to be immersed into seawater; and a temperature control device 17 located at an installation site of the pump device 30. In this corrosion protection system 70, a sacrificial anode 3 electrically conductive with the column pipe 33 and capable of being controlled in temperature is attached through a heating/cooling unit 11 and a thermal conduction sheet 10 to the column pipe 33. The temperature control device 17 is configured to control, based on the temperature of the sacrificial anode 3 measured by the measurement unit 20, the temperature of the sacrificial anode 3 using the heating/cooling unit 11 attached through the thermal conduction sheet 10 to the sacrificial anode 3.

FIG. 1



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Description

Technical Field

[0001] The present invention relates to corrosion protection system and pump device with the same, and particularly relates to a corrosion protection system suitable for use with a sacrificial anode and a pump device with the same.

Background Art

[0002] Patent Document 1 describes an example of conventional corrosion protection for a device used in a seawater environment. According to this document, in order to protect a duplex stainless steeled device fitted with an expandable graphite sealing material against corrosion, a duplex stainless steel member of the device adjoining and joined to a duplex stainless steel portion of the device fitted with the sealing material, thus forming an electric conductor integrally with the duplex stainless steel portion, is provided with one or more sacrificial anodes made of a metallic material having a lower normal electrode potential than the duplex stainless steel portion to be protected against corrosion, and the one or more sacrificial anodes are mounted and electrically connected to a surface of the duplex stainless steel member in contact with seawater fluid.

[0003] Furthermore, Patent Document 2 describes providing a seawater intake pump with a sacrificial anode and Patent Document 3 describes using magnesium alloy as a material for a sacrificial anode.

Citation List

Patent Document

[0004]

Patent Document 1: Japanese Patent Application Laid-Open No.2005-194624
Patent Document 2: Japanese Patent Application Laid-Open No. 2003-34886
Patent Document 3: Japanese Patent Application Laid-Open. No. Hei10-306388

Summary of the Invention

Technical Problem to be solved by the Invention

[0005] As for the sacrificial anode as described in Patent Documents 1 and 3, the rate of elution cannot be controlled unless the surface area or the mounting location of the sacrificial anode is changed. Specifically, in order to extend the life of the sacrificial anode to a predetermined value or more, an amount of anode material equal to or greater than the amount obtained by multiplying a previously measured amount of sacrificial anode reduced per unit time by a required life is necessary, in which case a vast sacrificial anode has to be mounted. As a result, although it is not so difficult to secure a location for mounting a vast sacrificial anode to a heat exchanger or so on which has plenty of space for mounting the sacrificial anode or allows easy mounting of additional sacrificial anodes, it is difficult to secure a location for mounting a vast sacrificial anode in the case where the mounting location of a sacrificial anode is very restrictive, such as a seawater pump. Furthermore, the magnitude of protection current flowing through the sacrificial anode depends on the electrolyte, the material and shape of an object to be protected against corrosion, and the shape of the sacrificial anode, which restricts the design of the corrosion protection system suitable to the object to be protected against corrosion.

[0006] A seawater intake pump device described in Patent Document 2 is designed to extend the life of the sacrificial anode by limiting the portion to be protected against corrosion by the sacrificial anode. In this case, however, it is difficult to cope with the occurrence of unexpected corrosion in portions other than the limited portion.

[0007] The present invention has been made in view of the above inconveniences of the known techniques and, therefore, an object of the present invention is to extend the life of a sacrificial anode for use in a pump device, such as a seawater pump, and thus extend the life of a corrosion protection system of the seawater pump device.

Solution to the Technical Problem

[0008] A feature of the present invention to achieve the above object is that a corrosion protection system comprises: a metallic member to be protected against corrosion; a sacrificial anode electrically conductively attached to the metallic member and capable of being controlled in temperature; and a temperature control device configured to control temperatures of the metallic member to be protected against corrosion and the sacrificial anode.

[0009] Another feature is a pump device including the corrosion protection system, wherein the metallic member to be protected against corrosion is a casing of the pump device and the sacrificial anode is electrically conductively attached to a portion of the casing to be immersed into an electrolyte.

Advantageous Effects of the Invention

[0010] According to the present invention, the temperature of the sacrificial anode for use in the pump device, such as a seawater pump, can be controlled to be a temperature different from the temperature of surrounding seawater into which the pump device is immersed. Therefore, the rate of elution of the sacrificial anode can be controlled, so that the life of the sacrificial anode can be extended. Thus, the lives of the pump device and the corrosion protection system provided in the pump device can be increased.

Brief Description of the Drawings

[0011]

[Fig. 1] Fig. 1 is a view of a schematic general structure of a desalination system including a pump device with a corrosion protection system according to one embodiment of the present invention.
[Fig. 2] Fig. 2 is a partially enlarged view of the pump device shown in Fig. 1.
[Fig. 3] Fig. 3 is a graph illustrating cathodic polarization curves of stainless steel SUS316L in seawater.
[Fig. 4] Fig. 4 is a graph illustrating cathodic polarization curves of duplex stainless steel S31803 in seawater.
[Fig. 5] Fig. 5 is a graph illustrating anodic polarization curves of zinc alloy in seawater.
[Fig. 6] Fig. 6 is a graph illustrating anodic polarization curves of carbon steel in seawater.
[Fig. 7] Fig. 7 is a graph illustrating corrosion protection current.
[Fig. 8] Fig. 8 is a schematic view of a first test equipment for measuring the density of current flowing through a sacrificial anode.
[Fig. 9] Fig. 9 is a schematic view of a second test equipment for measuring the density of current flowing through a sacrificial anode.
[Fig. 10] Fig. 10 is a flowchart showing a measuring method using a measuring device shown in Fig. 8.
[Fig. 11] Fig. 11 is a flowchart showing a measuring method using a measuring device shown in Fig. 9.
[Fig. 12] Fig. 12 is a view of a schematic structure of a corrosion protection system according to one embodiment of the present invention.
[Fig. 13] Fig. 13 is flowcharts showing measuring methods using a measuring device shown in Fig. 12, wherein Fig. 13(a) shows the case where a sacrificial anode is cooled and Fig. 13(b) shows the case where a sacrificial anode is heated.

Description of the Embodiments

[0012] In the case of using a metallic material as a casing material for a device for use in seawater or like environments likely to cause corrosion, for example, for an intake pump of a desalination pumping plant, one of a sacrificial anode corrosion protection method, an externally powered corrosion protection method, a surface coating method, and a high corrosion resistant material method is mainly used as a measure for reducing the occurrence of corrosion in the metallic material. Among them, the sacrificial anode corrosion protection method is performed by bringing a sacrificial anode relatively easily mountable and having low cost in materials and so on into contact with an object to be protected and is being commonly used in recent years.

[0013] The corrosion protection method is a corrosion protection method of controlling electron migration in corrosion action. In the sacrificial anode electrolytic protection method, a metallic material for use as a structural member of a device to be protected against corrosion is brought into contact with a metallic material having a lower normal electrode potential, i.e., a metallic material less noble in potential. The metallic material less noble in normal potential elutes metal ions in a solution environment to reach the same potential as the metallic material to be protected against corrosion and transfers electrons to the metallic material to be protected against corrosion. Meanwhile, the metallic material to be protected against corrosion transfers the potential to a cathode side which reduces an anode dissolution reaction owing to supply of the electrons, thus reducing an anode corrosion reaction. This lower-normal potential, less noble metallic material brought into contact with the metallic material to be protected against corrosion is a sacrificial anode.

[0014] Examples of the metallic material to be protected against corrosion include: iron and steel materials, such as cast iron, rolled steel, SC steel, dies steel, and nickel cast iron; copper alloys, such as bronze and brass; and nickel base alloys, such as cupronickel and monel. Furthermore, other materials to be protected against corrosion are rolled or cast stainless steels, such as austenite stainless steel, ferrite stainless steel, duplex stainless steel, martensite stainless steel, and precipitation hardened stainless steel. In contrast, materials for the sacrificial anode that can be used include carbon steel, aluminum, zinc, magnesium, and alloys containing any of these non-ferrous metals as a major ingredient. The sacrificial anode is consumed with the elution reaction. An impeller or so on of a seawater pump to be protected against corrosion is brought into contact with a sacrificial anode having a less noble normal potential and a large area to reduce corrosion because a structural member of the device to be protected against corrosion is likely to corrode.

[0015] A description will hereinafter be given of an example of a corrosion protection system using the above sacrificial anode and an example of a pump device including the corrosion protection system with reference to the drawings. Fig. 1 is a view showing a desalination system 80 and a view of a schematic general structure of the desalination system 80. Fig. 2 is an enlarged view of the portion X of the pump device shown in Fig. 1. The desalination system 80 includes a seawater intake pump 30 as the pump device.

[0016] In the desalination system 80, seawater 5 is introduced through a conduit 41 into an intake tank 42 provided near a shore 40. Essential portions of the pump device 30 including an intake portion are immersed in the intake tank 42. A discharge side of the pump device 30 is connected to a discharge pipe 43 and the discharge pipe 43 is led to a dual filter 44 operable to filter foreign substances, such as sand, in seawater taken in by the pump device 30.

[0017] The seawater 5 filtered by the dual filter 44 is conducted to a filtered-seawater tank 45. Then, the seawater is supplied to a protective filter 47 by a pump 46 provided in the filtered-seawater tank 45. The seawater from which foreign substances, including iron particles, have been removed by the protective filter 47 is sent to a high-pressure pump 49 to which a power recovery turbine 50 is connected. The seawater increased in pressure by the high-pressure pump 49 is supplied through a pipe 48 to an RO membrane (reverse osmosis membrane) module 52, converted into fresh water in the RO membrane module 52 by removing salt and like matters, conducted through a pipe 53, and reserved in a product water tank 54. Meanwhile, concentrated water obtained by reducing water in the RO membrane module 52 is conducted through a pipe 51 to the power recovery turbine 50 and energy of the concentrated water is recovered as part of the power for driving the high-pressure pump 49. The concentrated water reduced in pressure by the power recovery in the power recovery turbine 50 is sent through a pipe 55 to the outside of the desalination system 80.

[0018] As will be described later in detail, the inside and outside surfaces of a lifting pipe of the pump device 30 are immersed in seawater. Furthermore, the inside surfaces of the high-pressure pump 49 and the pump 46 are in contact with seawater. Therefore, these surfaces are under corrosion-prone environment. In addition, metal pipes are used as the pipes downstream of the high-pressure pump 49, wherein seawater flows through them at an internal pressure of 5 MPa or more. In these metal pipes, corrosion phenomena depending upon the salt concentration occur with time and corrosion may progress at a high reaction rate particularly at their flanges as pipe joints and their welded portions non-uniform in surface structure and surface roughness. A corrosion protection system 70 of this embodiment is necessary to prevent the occurrence of corrosion in these portions.

[0019] The seawater intake pump serving as the pump device 30 is a vertical shaft pump in this embodiment, wherein a suction bell mouth 34 is mounted to the distal end of the pump. A pump casing 33 is flange-connected to the suction bell mouth 34 and the impeller casing 33 is flange-connected at the downstream side with a guide vane 32. The downstream side of the guide vane 32 is flange-connected at flanges 35 with a lifting pipe (column pipe) 31. An installation unit 39 for securing the seawater intake pipe 30 thereto is mounted on an axially intermediate portion of the lifting pipe 31 and fixed to a base plate 42a covering the top of the intake tank 42. The suction bell mouth 34, the impeller casing 33, the guide vane 32, and the lifting pipe 31 constitute a casing.

[0020] In contrast in the interior of the casing, a rotary shaft 36 extends in a vertical direction and an impeller 38 is mounted to the lowermost end of the rotary shaft 36 and fixed to the rotary shaft 36 by an impeller nut and so on. On the inner peripheral side of the guide vane 32, a guide vane inner wall 37 is disposed which gradually reduces the diameter toward the downstream side to form a guide vane channel. A measurement unit 20 includes a sacrificial anode 3 and a heating/cooling unit 11. The heating/cooling unit 11 is attached through a thermal conduction sheet 10 to one side of the sacrificial anode 3. The sacrificial anode 3, the thermal conduction sheet 10, and the heating/cooling unit 11 are fastened to the outside wall surface of the column pipe 31 by an electrically conductive fastener 4, for example, a bolt. Furthermore, a temperature detector 12 is attached to the sacrificial anode 3. The details of the corrosion protection system 70 provided for the seawater intake pump 30 will be described later.

[0021] Next, a description will be given of polarization curves providing important indices for the amount of consumption of the sacrificial anode 3. Results obtained by determining polarization curves of some structural materials serving as the above sacrificial anode and a cathode are shown below. The potential and current density of a metal in seawater are determined by a specific polarization curve. When two types of metals are in contact with each other in seawater, the potential is at the intersection point between their two types of polarization curves (a mixed potential), so that a protection current flows with a current density at the intersection point. The polarization of a metal is caused by an electrochemical reaction at the interface between an electrolyte and the metal. The polarization curve also depends upon temperature because the electrochemical reaction depends upon temperature. Therefore, with the temperature as a parameter, an optimum corrosion protection system can be designed with consideration for other effects.

[0022] Figs. 3 to 6 show the results obtained by determining the polarization characteristics of some materials. In determining the polarization characteristics, artificial seawater (Aquamarine manufactured by Yashima Pure Chemicals Co., Ltd.) was used as seawater. The test conditions were made so that dissolved oxygen was atmospherically saturated, the flow rate V of seawater was adjusted to V=0 (m/s), and the pH was adjusted to 8.2. The electrical conductivity EC was EC=5 (S/m).

[0023] Fig. 3 is a logarithmically approximated graph of cathodic polarization characteristics of stainless steel SUS316L and shows results obtained by determining them with the seawater temperature as a parameter. Stainless steel SUS316L is a material conventionally used for such a member as the column pipe 31 of the seawater intake pump 30 shown in Fig. 1 and was tested herein as a candidate for a metal to be protected against corrosion. Based on the potentials of the pipe made of stainless steel SUS316L and the sacrificial anode attached to the pipe in the case where the corrosion protection system is employed, the current between the pipe and the sacrificial anode is determined from the intersection point between a cathodic polarization curve shown in Fig. 3 and an anodic polarization curve of the sacrificial anode to be described later.

[0024] For the cathodic polarization of stainless steel SUS316L, a polarization voltage difference due to a seawater temperature difference is slight when the current density is up to about 10^1 ($\mu A/cm^2$), whereas in a range of current densities of 10^1 to 10^2 ($\mu A/cm^2$) the polarization voltage is highly temperature-dependent and the amount of change in polarization voltage is large. Furthermore, when the current density exceeds 10^2 ($\mu A/cm^2$), the polarization voltage is still temperature-dependent but the amount of change in polarization voltage is relatively small.

[0025] Fig. 4 shows in a graph results obtained by testing duplex stainless steel S31803 as another candidate material for the pipe material by logarithmically approximating cathodic polarization characteristics in the same manner as in Fig. 3. The seawater temperature was employed as a parameter. Duplex stainless steel S31803 is being increasingly used as a material for a seawater pump required to have higher corrosion resistance. Also in Fig. 4, in a range of current densities of 10^1 to 10^2 ($\mu A/cm^2$), the polarization voltage is highly temperature-dependent and the amount of change in polarization voltage is large. Furthermore, in the range of current densities of 10^1 to 10^2 ($\mu A/cm^2$) in both of Figs. 3 and 4, the polarization voltage reaches a maximum at a seawater temperature of 40°C. In other words, under the same voltage condition, the current density is minimum.

[0026] Fig. 5 shows a graph in which zinc alloy as a candidate material for the sacrificial anode was logarithmically approximated in terms of anodic polarization characteristics. The graph is results of a test performed with the seawater temperature as a parameter. The test conditions are the same as those in the test for the cathodic polarization characteristics. The zinc alloy used was ZAP-A (EL) (hereinafter referred to as zinc alloy) manufactured by Mitsui Sumitomo Metal Mining Brass & Copper Co., Ltd. This zinc alloy has a composition in which pure zinc is doped with aluminum as an alloy element.

[0027] In comparison at the same potential in Fig. 5, the current density is minimum at a seawater temperature of 40°C and the current density in a range of seawater temperatures of 30 to 50°C is significantly reduced as compared with that in a range of seawater temperatures of 20 to 25°C. Therefore, it can be seen that in the case of a sacrificial anode made of zinc alloy, the life of the sacrificial anode can be extended if the temperature of seawater in contact with the sacrificial anode is adjusted to be 30 to 50°C. Furthermore, it can be expected that the life can be most extended at a seawater temperature of 40°C.

[0028] Fig. 6 shows a graph in which carbon steel as another candidate material for the sacrificial anode was logarithmically approximated in terms of anodic polarization characteristics. The seawater temperature is shown as a parameter. The test conditions are the same as those in the test shown in Fig. 5. SS400 was used as carbon steel. In the case of the carbon steel shown in Fig. 6, in comparison at the same potential, the carbon steel reduces the current density as the temperature of seawater in contact with the carbon steel becomes lower, unlike the zinc alloy shown in Fig. 5. Therefore, in the case of using carbon steel as the sacrificial anode, it can be expected to extend the life more by making the temperature of seawater in contact with the carbon steel as low as possible.

[0029] Next, a description will be given of, taking as an example the case where austenite stainless steel SUS316L was used as a cathode material and zinc alloy was used as a sacrificial anode, a specific method for determining a change in generated current density due to seawater temperature with reference to the above results and Fig. 7. Fig. 7 is obtained by combining Figs. 3 and 5. For the sake of avoiding the figure from complication, Fig. 7 shows as representatives only the logarithmically approximate curve 100 of the cathodic polarization of stainless steel SUS316L at 25°C and the logarithmic approximation curve 101 of the anodic polarization of zinc alloy at 25°C.

[0030] It can be seen from the intersection point in Fig. 7 that the potential and current density when SUS316L and zinc alloy are short-circuited in seawater under conditions of a seawater temperature of 25°C and a sacrificial anode (zinc alloy) temperature of 25°C are -1.074 V and 97.0 $\mu A/cm^2$, respectively. When the intersection points between the cathode curve 100 and the logarithmically approximate curves of the anodic polarizations of zinc alloy at 20°C, 30°C, 40°C, and 50°C are determined in the same manner, they are represented as the solid circles described on the cathode curve 100. The potential and current density at each of these temperatures can be determined from the intersection point between both the curves at the temperature.

[0031] In this relation, with the use of approximate equations, the potential and current density during corrosion protection can be estimated more promptly by calculation. For example, a neighborhood of the intersection point between the cathode curve 100 and the anode curve 101 at 25°C is approximated using Equation 1 below in terms of the cathode curve 100 and Equation 2 below in terms of the anode curve 101. By solving both the equations as a system of equations, the potential and current density at the intersection point can be determined.

[Math. 1]

$$V=-0.4240\times\log(i)-0.2316 \ldots \text{(Equation 1)}$$

[Math. 2]

$$V=-0.0305\times\log(i)-1.1346 \ldots \text{(Equation 2)}$$

where V represents a potential (V vs. SCE) and i represents a current density ($\mu A/cm^2$).

[0032] Approximation methods that can be used include, in addition to the logarithmic approximation method, the linear approximation method, the polynomial approximation method, and the exponential approximation method. Furthermore, with the use of approximate equations of these methods, a potential distribution and a current density distribution can be determined and designed by simulation using a known method, such as the finite element method or the boundary element method. Note that polarization curves may be used without approximation, in which case the potential and current density during corrosion protection can be estimated with high accuracy.

[0033] In the sacrificial anode corrosion protection system, a potential difference between the metallic member to be protected against corrosion and the sacrificial anode in the electrolyte serves as a driving force to generate current. The electrolyte may be, besides seawater, fresh water, brackish water, brine, salt water or so on. In general, when these waters are classified according to the sodium chloride concentration, water having a sodium chloride concentration of less than 0.05% is referred to as fresh water, water having a sodium chloride concentration of more than 0.05% but less than 0.35% is referred to as brackish water, water having a sodium chloride concentration of more than 0.35% but less than 0.5% is referred to as brine, and water having a sodium chloride concentration of 0.5% or more is referred to as salt water. The sodium chloride concentration of seawater is about 0.24% to about 2.96% and differs by marine area. Alternatively, an aqueous solution containing any ionic species is also applicable as the electrolyte.

[0034] In Figs. 3 to 7, the current density generated in the sacrificial anode was determined under the condition where all of the seawater, the sacrificial anode, and the cathode material as a structural member had the same temperature. In the present invention, only the sacrificial anode is temperature-controllable in order to reduce the amount of consumption of the sacrificial anode. A description will hereinafter be given of test results in the case where the temperature of the sacrificial anode was changed with respect to the seawater temperature.

[0035] Fig. 8 shows in schematic view a first test equipment 61 for a corrosion protection system in which a seawater intake pump is simulated and Fig. 9 shows in schematic view a second test equipment 62 likewise. In both the test equipment 61 and 62, both the surfaces of a simulated member (simulated pipe member) 1 to be protected against corrosion as a cathode material and a sacrificial anode 3 are brought into contact with artificial seawater 6.

[0036] Specifically, in the first test equipment 61, a vessel 21 in which artificial seawater 6 is reserved by a predetermined amount is placed in a water bath 8 accumulating water 7. A test piece of the simulated pipe member 1 is suspended in the vessel 21 by using a cable 15e also as a support member. Likewise, the sacrificial anode 3 is suspended in the vessel 21 by using a cable 15f also as a support member. A heating/cooling unit 11 is attached through a thermal conduction sheet 10 to one side of the sacrificial anode 3. The heating/cooling unit 11 is connected to a control unit 13 by a cable 15b. A temperature detector 12a is attached to the sacrificial anode 3 and temperature information detected by the temperature detector 12a is input through a cable 15c to the control unit 13. The control unit 13 is connected to a power supply 14 by a cable 15a. The simulated pipe member 1 and the sacrificial anode 3 are connected through a zero-shunt ammeter 9 to each other by cables 15e and 15f.

[0037] The second test equipment 62 includes the same components as those in the first test equipment 61 and further includes a second temperature detector 12b. The second temperature detector 12b is configured to detect the temperature of the artificial seawater 6 and temperature information detected by the second temperature detector 12b is input through a cable 15d to the control section 13.

[0038] Although in the above test equipment 61 and 62 the simulated pipe member 1 and the sacrificial anode 3 are electrically conductively connected using the zero-shunt ammeter 9 and the cables 15e and 15f, the simulated pipe member 1 and the sacrificial anode 3 may be fastened by an electrically conductive fastener 4, such as a bolt, or brought into direct contact with each other. By these configurations, the sacrificial anode 3 can reduce the potential of the simulated pipe member 1 to a lower potential than the immersion potential of the simulated pipe member 1 itself.

[0039] Each of the first and second test equipment 61 and 62 is provided with a temperature control device 17 to enable the control over the temperature of a portion of the sacrificial anode 3 in contact with the artificial seawater 6. The temperature control device 17 includes a measurement unit 20 attached to the sacrificial anode 3 and a control device 16 disposed at a location where an installation site of the seawater intake pump is simulated. The measurement unit 20 is composed of the heating/cooling unit 11 and the temperature detectors 12a and 12b and the control device 16 is composed of the control unit 13 and the power supply 14.

[0040] An electrical heating wire sealed to keep it from direct contact with the artificial seawater 6 is used as the heating/cooling unit 11 and disposed at a location where it makes thermal contact with the sacrificial anode 3. Alternatively, a Peltier element, a heat exchanger or so on may be used as the heating/cooling unit 11. To reduce the thermal resistance between the heating/cooling unit 11 and the sacrificial anode 3, they are preferably bonded together by a thermal conduction sheet 10 as shown in Figs. 8 and 9. Alternatively, a heat conductive grease may be used.

[0041] A sheathed thermocouple is used as each of the temperature detectors 12a and 12b. Instead of the sheathed thermocouple, various means, including a sheath-free thermocouple and a resistance thermometer, may be used. Temperature information obtained by measurement with the temperature detectors 12a and 12b is input to the control unit 13 and the surface temperature of the sacrificial anode 3 is feedback-controlled to a predetermined temperature.

[0042] The temperature information is visually displayed on a display attached to an unshown image processing device provided in the control device 16. This temperature information is used to monitor the surface temperature of the sacrificial anode 3. Each test equipment is configured so that the temperature information can be output as information after being recorded in a recording device. To enable the measurement of a portion of the sacrificial anode 3 in contact with the artificial seawater 6, the temperature detector 12 is placed on a surface of the sacrificial anode 3 coming into contact with the artificial seawater 6. In this case, the areas of the temperature detectors 12a and 12b are made as small as possible.

[0043] The control unit 13 controls the output of the heating/cooling unit 11 based on the information from the temperature detectors 12a and 12b. The power supply 14 supplies electric power to the sacrificial anode 3 and the control unit 13. The control unit 13 and the power supply 14 are preferably placed at locations distant from the sacrificial anode 3 and provided at locations where they are kept from direct contact with the artificial seawater 6, as in the test equipment 61 and 62.

[0044] Fig. 8 shows in a flowchart the procedure for controlling the temperature control device 17 in performing a corrosion protection test using the first test equipment 61. In the first test equipment 61, the first temperature detector 12a for measuring the temperature of the sacrificial anode 3 is placed at a portion of the sacrificial anode 3 in contact with the artificial seawater 6.

[0045] In step S110, a set temperature T_0 serving as a minimum value (in the case of using a heater as the heating/cooling unit 11) or a maximum value (in the case of using a cooler as the heating/cooling unit 11) of a testing range previously determined according to the material of the sacrificial anode 3 used is input through the control unit 13. Next, the temperature T_1 of the sacrificial anode 3 is measured with the first temperature detector 12a attached to the portion of the sacrificial anode 3 in contact with the artificial seawater 6 (step S120). The control unit 13 performs temperature control using the heating/cooling unit 11 so that the deviation between two temperatures T_0 and T_1 is reduced (step S130). Subsequently, the temperature T_1' of the sacrificial anode 3 is measured with the first temperature detector 12a (step S140). The set temperature T_0 is compared with T_1' in step S150. If the difference between the two temperatures T_0 and T_1' is in an allowable temperature range, the flow is ended and the test goes to the next temperature measurement point. If the temperature difference is out of the allowable temperature range, the flow goes back to step S120. When the measurement at all the measurement points is finished, the test is ended.

[0046] In the second test equipment 62 shown in Fig. 9, the second temperature detector 12b for measuring the artificial seawater temperature T_2 near the sacrificial anode 3 is placed in addition to the configuration of the first test equipment 61 shown in Fig. 8. The same device as the first temperature detector 12a is used as the second temperature detector 12b. Temperature signals detected by the two temperature detectors 12a and 12b are input to the control unit 13. In the test using the second test equipment 62, the control unit 13 controls the temperature of the sacrificial anode 3 so that the difference (an absolute value) between the detected temperatures is in a predetermined range.

[0047] Fig. 11 shows in a flowchart a testing method using the second test equipment 62. Specifically, in step S210, the seawater temperature T_2 is set at one of 25°C, 30°C, 40°C, and 50°C and the difference ΔT between the seawater temperature T_2 and the temperature T_1 serving as a minimum value (in the case of using a heater as the heating/cooling unit 11) or a maximum value (in the case of using a cooler as the heating/cooling unit 11) of a testing range previously determined according to the material of the sacrificial anode 3 used is input through the control unit 13. Next, the seawater temperature T_2 is measured with the second temperature detector 12b for measuring the seawater temperature T_2 near the sacrificial anode 3 (step S220).

[0048] The temperature T_1 of the sacrificial anode 3 is detected with the first temperature detector 12a attached to the portion of the sacrificial anode 3 in contact with the artificial seawater 6 (step S230). The control unit 13 performs temperature control using the heating/cooling unit so that the temperature difference ΔT between the two temperatures

T_2 and T_1 approaches a predetermined value (step S240). Subsequently, the temperature T_1' of the sacrificial anode 3 is measured with the first temperature detector 12a (step S250).

[0049] The seawater temperature T_2 detected by the second temperature detector 12b is compared with the temperature T_1' of the sacrificial anode 3 in step S260. If the difference between the two temperatures T_2 and T_1' is in a predetermined allowable range for the temperature difference ΔT, the flow is ended and the test goes to the next temperature measurement point for obtaining the next temperature difference ΔT. If the difference between the two temperatures T_2 and T_1' is out of the allowable set temperature range, the flow goes back to step S230. When the measurement at all the measurement points is finished (step S260), the test is ended.

[0050] A description will be given below of results of tests using stainless steel SUS316L and duplex stainless steel S31803 as pipe materials for a cathode and zinc alloy and SC steel SS400 as materials for a sacrificial anode and using the above two test equipment and two testing methods.

(A Series)

[0051] This series is in the case where stainless steel SUS316L was used as the simulated pipe member 1 serving as a cathode material and zinc alloy was used as the sacrificial anode 3. Using the first test equipment 61 and the first testing method, the seawater temperature T_2 was changed between 25 and 50°C and the temperature T_1 of the sacrificial anode 3 was changed between 20 and 50°C. The simulated pipe member 1 and the sacrificial anode 3 were connected by the zero-shunt ammeter 9 and the current density flowing between the simulated pipe member 1 and the sacrificial anode 3 was measured. Note that considering that seawater in the pump might be raised in temperature by power applied from the impeller, the following series of tests were conducted also in the case where the seawater temperature T_2 rose to 50°C. Table 1 below shows test results by arranging each test result by the test number, the set conditions (seawater temperature and sacrificial anode temperature), and the test result (current density).

[0052] [Table 1]

Table 1

TEST No.	SET CONDITIONS		TEST RESULT
	SEAWATER TEMP. (°C)	SACRIFICIAL ANODE TEMP. (°C)	CURRENT DENSITY ($\mu A/cm^2$)
A1	25	20	99.4
A2	25	25	97.0
A3	25	30	88.2
A4	25	40	74.5
A5	25	50	79.4
A6	30	20	127.5
A7	30	25	121.0
A8	30	30	101.0
A9	30	40	77.9
A10	30	50	82.6
A11	40	20	300.6
A12	40	25	287.9
A13	40	30	245.1
A14	40	40	188.4
A15	40	50	207.3
A16	50	20	207.0
A17	50	25	196.8
A18	50	30	163.8
A19	50	40	125.6
A20	50	50	134.3

[0053] Table 2 is a summary of the above test results. In Table 2, "cross" indicates that the temperature of the sacrificial anode 3 is not suitable as its operating temperature, "open circle" indicates that the temperature of the sacrificial anode 3 is suitable as its operating temperature, and "double circle" indicates that the temperature of the sacrificial anode 3 is particularly effective as its operating temperature.

[0054] The determination of whether the temperature T_1 of the sacrificial anode 3 was suitable or unsuitable as the operating temperature was made with reference to determine the temperature T_1 to be suitable if it was in a range of, among temperatures of the sacrificial anode 3 changed between 20 and 50°C, temperatures at which the current density was small.

[0055] [Table 2]

Table 2

A SERIES		SACRIFICIAL ANODE TEMP. (°C)				
		20	25	30	40	50
SEAWATER TEMP. (°C)	25	cross	cross	open circle	double circle	open circle
	30	cross	cross	open circle	double circle	open circle
	40	cross	cross	open circle	double circle	open circle
	50	cross	cross	open circle	double circle	open circle

[0056] As shown in Table 1, within the test numbers A1 to A20, when the temperature T_1 of the sacrificial anode 3 was from 30°C to 50°C, the current density between the simulated pipe member 1 of stainless steel SUS316L and the sacrificial anode 3 was small as compared with when the temperature T_1 of the sacrificial anode 3 was 20°C or 25°C. It was found from these results that in the above combination of the cathode material and the anode material, life extension of the sacrificial anode 3 can be expected by controlling the temperature T_1 of the sacrificial anode 3 to a higher temperature than a predetermined temperature.

(B Series)

[0057] This series is in the case where stainless steel SUS316L was used as the simulated pipe member 1 serving as a cathode material and SC steel SS400 was used as the sacrificial anode 3. Using the second test equipment 62 and the second testing method, the seawater temperature T_2 was changed between 25 and 50°C and the temperature T_1 of the sacrificial anode 3 was changed between 10 and 50°C using a Peltier element as the cooler. Here, based on temperature signals detected by the first temperature detector 12a for detecting the temperature T_1 of the sacrificial anode 3 and the second temperature detector 12b for detecting the seawater temperature T_2, temperature control was made so that the temperature T_1 of the sacrificial anode 3 was lower than the seawater temperature T_2. Furthermore, the simulated pipe member 1 and the sacrificial anode 3 were connected by the zero-shunt ammeter 9 and the current density flowing between the simulated pipe member 1 and the sacrificial anode 3 was measured. Table 3 below shows test results by arranging each test result by the test number, the set conditions (seawater temperature and sacrificial anode temperature), and the test result (current density).

[0058] [Table 3]

Table 3

TEST No.	SET CONDITIONS		TEST RESULT
	SEAWATER TEMP. (°C)	SACRIFICIAL ANODE TEMP. (°C)	CURRENT DENSITY ($\mu A/cm^2$)
B1	25	10	26.3
B2	25	20	29.1
B3	25	25	29.3
B4	30	10	32.6
B5	30	20	36.4
B6	30	25	36.8

(continued)

TEST No.	SET CONDITIONS		TEST RESULT
	SEAWATER TEMP. (°C)	SACRIFICIAL ANODE TEMP. (°C)	CURRENT DENSITY (μA/cm^2)
B7	30	30	37.1
B8	40	10	52.2
B9	40	20	58.5
B10	40	25	60.1
B11	40	30	60.7
B12	40	40	64.1
B13	50	10	47.7
B14	50	20	53.9
B15	50	25	55.3
B16	50	30	55.9
B17	50	40	59.2
B18	50	50	61.4

[0059] Table 4 shows a summary of the test results. In Table 4, "cross" indicates that the temperature of the sacrificial anode 3 is not suitable as its operating temperature, "open circle" indicates that the temperature of the sacrificial anode 3 is suitable as its operating temperature, and "double circle" indicates that the temperature of the sacrificial anode 3 is particularly effective as its operating temperature. Note that "minus" indicates that because it was predicted that no effect could be obtained, the test was not carried out. The determination of whether the temperature T_1 of the sacrificial anode 3 was suitable or unsuitable as the operating temperature was made by, with reference to the current density when the seawater temperature T_2 was equal to the temperature T_1 of the sacrificial anode 3, determining the temperature T_1 to be suitable if the current density at the temperature T_1 in question was lower than the current density at the temperature T_1 equal to the seawater temperature T_2.

[0060] [Table 4]

Table 4

B SERIES		SACRIFICIAL ANODE TEMP. (°C)					
		10	20	25	30	40	50
SEAWATER TEMP. (°C)	25	double circle	open circle	cross	minus	minus	minus
	30	double circle	open circle	open circle	cross	minus	minus
	40	double circle	open circle	open circle	open circle	cross	minus
	50	double circle	open circle	open circle	open circle	open circle	cross

[0061] As shown in Table 3, within the test numbers B1 to B18, when the temperature T_1 of the sacrificial anode 3 was lower than the seawater temperature T_2, the current density between the simulated pipe member 1 of stainless steel SUS316L and the sacrificial anode 3 was smaller than when the temperature T_1 of the sacrificial anode 3 was equal to the seawater temperature T_2. It was found form these results that in the above combination of the cathode material and the anode material, life extension of the sacrificial anode 3 can be expected by controlling the temperature T_1 of the sacrificial anode 3 to a lower temperature than the seawater temperature T_2.

(C Series)

[0062] This series is in the case where duplex stainless steel S31803 was used as the simulated pipe member 1 serving as a cathode material and zinc alloy was used as the sacrificial anode 3. Using the first test equipment 61 and the first testing method, the seawater temperature T_2 was changed between 25 and 50°C and the temperature T_1 of the sacrificial anode 3 was changed between 20 and 50°C. The simulated pipe member 1 and the sacrificial anode 3 were connected by the zero-shunt ammeter 9 and the current density flowing between the simulated pipe member 1 and the sacrificial anode 3 was measured. Table 5 below shows test results by arranging each test result by the test number, the set conditions (seawater temperature and sacrificial anode temperature), and the test result (current density).

[0063] [Table 5]

Table 5

TEST No.	SET CONDITIONS		TEST RESULT
	SEAWATER TEMP. (°C)	SACRIFICIAL ANODE TEMP. (°C)	CURRENT DENSITY (μA/cm^2)
C1	25	20	82.1
C2	25	25	78.2
C3	25	30	63.5
C4	25	40	50.1
C5	25	50	51.6
C6	30	20	108.5
C7	30	25	102.9
C8	30	30	84.8
C9	30	40	62.3
C10	30	50	68.2
C11	40	20	239.2
C12	40	25	228.4
C13	40	30	193.0
C14	40	40	145.2
C15	40	50	161.4
C16	50	20	153.6
C17	50	25	145.6
C18	50	30	120.6
C19	50	40	99.5
C20	50	50	101.4

[0064] Table 6 shows a summary of the test results. In Table 6, "cross" indicates that the temperature of the sacrificial anode 3 is not suitable as its operating temperature, "open circle" indicates that the temperature of the sacrificial anode 3 is suitable as its operating temperature, and "double circle" indicates that the temperature of the sacrificial anode 3 is particularly effective as its operating temperature.

[0065] [Table 6]

Table 6

C SERIES		SACRIFICIAL ANODE TEMP. (°C)				
		20	25	30	40	50
SEAWATER TEMP. (°C)	25	cross	cross	open circle	double circle	open circle
	30	cross	cross	open circle	double circle	open circle
	40	cross	cross	open circle	double circle	open circle
	50	cross	cross	open circle	double circle	open circle

[0066] As shown in Table 5, within the test numbers C1 to C20, when the temperature T_1 of the sacrificial anode 3 was from 30°C to 50°C, the current density between the simulated pipe member 1 of duplex stainless steel S31803 and the sacrificial anode 3 was small as compared with when the temperature T_1 of the sacrificial anode 3 was 20°C or 25°C. It was found from these results that in the above combination of the cathode material and the anode material, life extension of the sacrificial anode 3 can be expected by controlling the temperature T_1 of the sacrificial anode 3 to a higher temperature than a predetermined temperature, for example, 30°C.

(D Series)

[0067] This series is in the case where duplex stainless steel S30803 was used as the simulated pipe member 1 serving as a cathode material and SC steel SS400 was used as the sacrificial anode 3. Using the second test equipment 62 and the second testing method, the seawater temperature T_2 was changed between 10 and 50°C and the temperature T_1 of the sacrificial anode 3 was changed between 20 and 50°C. The temperature T_1 of the sacrificial anode 3 was changed between 10 and 50°C using a Peltier element as the cooler. Here, based on temperature signals detected by the first temperature detector 12a for detecting the temperature T_1 of the sacrificial anode 3 and the second temperature detector 12b for detecting the seawater temperature T_2, temperature control was made so that the temperature T_1 of the sacrificial anode 3 was lower than the seawater temperature T_2. The simulated pipe member 1 and the sacrificial anode 3 were connected by the zero-shunt ammeter 9 and the current density flowing between the simulated pipe member 1 and the sacrificial anode 3 was measured. Table 7 below shows test results by arranging each test result by the test number, the set conditions (seawater temperature and sacrificial anode temperature), and the test result (current density).

[0068] [Table 7]

Table 7

TEST No.	SET CONDITIONS		TEST RESULT
	SEAWATER TEMP. (°C)	SACRIFICIAL ANODE TEMP. (°C)	CURRENT DENSITY (μA/cm^2)
D1	25	10	32.9
D2	25	20	44.3
D3	25	25	44.5
D4	30	10	32.3
D5	30	20	35.2
D6	30	25	35.4
D7	30	30	35.6
D8	40	10	52.6
D9	40	20	58.5
D10	40	25	60.0
D11	40	30	60.7
D12	40	40	63.8
D13	50	10	50.9
D14	50	20	55.4
D15	50	25	56.5
D16	50	30	57.0
D17	50	40	59.3
D18	50	50	60.8

[0069] Table 8 shows a summary of the test results. In Table 8, "cross" indicates that the temperature of the sacrificial anode 3 is not suitable as its operating temperature, "open circle" indicates that the temperature of the sacrificial anode 3 is suitable as its operating temperature, and "double circle" indicates that the temperature of the sacrificial anode 3 is particularly effective as its operating temperature. "Minus" indicates that because it was predicted that no effect could be obtained, the test was not carried out.

[0070] [Table 8]

Table 8

D SERIES		SACRIFICIAL ANODE TEMP. (°C)					
		10	20	25	30	40	50
SEAWATER TEMP. (°C)	25	double circle	open circle	cross	minus	minus	minus
	30	double circle	open circle	open circle	cross	minus	minus
	40	double circle	open circle	open circle	open circle	cross	minus
	50	double circle	open circle	open circle	open circle	open circle	cross

[0071] As shown in Table 7, within the test numbers D1 to D18, when the temperature T_1 of the sacrificial anode 3 was lower than the seawater temperature T_2, the current density between the duplex stainless steel S31803 and the sacrificial anode 3 was smaller than when the temperature T_1 of the sacrificial anode 3 was equal to the seawater temperature T_2. It was found form these results that in the above combination of the cathode material and the anode material, life extension of the sacrificial anode 3 can be expected by controlling the temperature T_1 of the sacrificial anode 3 to a lower temperature than the seawater temperature T_2. In particular, when the temperature of the sacrificial anode 3 was decreased to 10°C, the current density was minimum, resulting in the most preferred result for life extension of the sacrificial anode 3.

[0072] The test equipment 61 and 62 using the above simulated pipe member 1 is applicable to the corrosion protection system for the pump device 30 as it is. Furthermore, the above temperature control methods can be used for optimum temperature control of the corrosion protection system by adding modification, because the temperature of the sacrificial anode 3 can be set by measuring the seawater temperature instead of the artificial seawater temperature.

First Embodiment

[0073] Fig. 12 shows a corrosion protection system considered for application to an actual pump device 30 with the reflection of the above results of the tests including some combinations of the simulated pipe member 1 and the sacrificial anode 3 using the first and second test equipment 61 and 62. Fig. 12 is a front cross-sectional view of a third test equipment 63 for a corrosion protection system, capable of being diverted to an actual system.

[0074] Fig. 13 shows in flowcharts testing methods using the third test equipment 63. First, a description will be given of the case where the sacrificial anode 3 is cooled as shown in Fig. 13(a). Specifically, in step S310, a minimum value T_{max} and a maximum value T_{min} of a testing range previously determined according to the material of the sacrificial anode 3 used are set and input through the control unit 13. Hereinafter, a temperature control loop is started. The number of loop times is counted as an n-th loop and the initial value is n=0 (step S320). First, the current i_0 is detected with the zero-shunt ammeter 9 and the temperature T_0 of the sacrificial anode 3 is detected with the first temperature detector 12a (step S330). Next, the sacrificial anode 3 is cooled by the heating/cooling unit 11 (step S340), the flow proceeds to an n+1-th loop, i.e., a first loop (step S350), the current i_1 is detected with the zero-shunt ammeter 9, and the temperature T_1 of the sacrificial anode is detected with the first temperature detector 12a (step S360). A comparison between i_0 and i_1 is made (step S370). If i_1 is smaller, a comparison between T_1 and T_{min} is made (step S380). If T_1 is higher, the sacrificial anode 3 is cooled again by the heating/cooling unit 11 (step S340) and the flow then proceeds to an n+1-th loop, i.e., a second loop (step S350). If T_1 is lower, the sacrificial anode 3 is heated by the heating/cooling unit 11 to return it to the predetermined temperature range (step S390) and the flow then proceeds to an n+1-th loop, i.e., a second loop (step S350). Thereafter, the temperature control is repeated likewise. If in the comparison between i_1 and i_0 (step S400) the difference between them is in an allowable temperature range, the current value is determined to be at its minimum, the temperature T_1 of the sacrificial anode 3 is maintained (step S410), the temperature control flow is ended, and the test goes to the next temperature measurement point. On the other hand, if i_1 is greater, it is determined that the sacrificial anode 3 is excessively cooled, the sacrificial anode 3 is heated by the heating/cooling unit 11 (step S390), and the flow then proceeds to an n+1-th loop, i.e., a second loop (step S350). Thereafter, the temperature control is repeated likewise. When the measurement at all the measurement points is finished, the test is ended. In the case where the sacrificial anode 3 is heated as shown in Fig. 13(b), the temperature control can be performed by taking the heating and cooling in the description of Fig. 13(a) in the opposite sense. However, in step S381, a comparison is made between T_n and T_{max}. If T_n is lower, the sacrificial anode 3 is heated by the heating/cooling unit 11 (S341) and the flow then proceeds to an n+1-th loop (step S350). If T_n is higher, the sacrificial anode 3 is cooled by the heating/cooling unit 11 to return it to the predetermined temperature range (step S391) and the flow then proceeds to an n+1-th loop (step S350). Thereafter, the temperature control is repeated likewise.

[0075] Stainless steel SUS316L is used as a material for the simulated pipe member 1 and zinc alloy is used as the sacrificial anode 3 (Test No. E1). The temperature of the sacrificial anode 3 is controlled with the heating/cooling unit 11 so that the current value detected by the zero-shunt ammeter 9 for measuring the current value between the sacrificial anode 3 and the simulated pipe member 1 becomes smaller. In the temperature range of the artificial seawater 6 of 25°C to 50°C, the current density becomes smaller when the temperature of the sacrificial anode 3 is in a range of 30°C to 50°C. Furthermore, the current density exhibits a minimum value when the temperature of the sacrificial anode 3 is 40°C.

[0076] Stainless steel SUS316L is used as a material for the simulated pipe member 1 and carbon steel is used as the sacrificial anode 3 (Test No. E2). The other configurations are the same as in Test No. E1. In the temperature range of the artificial seawater 6 of 25°C to 50°C, the current density becomes smaller when the temperature of the sacrificial anode 3 is lower than the temperature of the artificial seawater 6. Furthermore, the current density exhibits a minimum value when the temperature of the sacrificial anode 3 is 10°C.

[0077] Two materials of stainless steel SUS316L and cast iron FC200 are used as materials for the simulated pipe member 1 and zinc alloy is used as the sacrificial anode 3 (Test No. E3). A gap is provided by bringing the stainless steel into contact with a gap tool. The corrosion protection is combined with an additional externally powered corrosion protection in which a platinum electrode is used. The stainless steel and the carbon steel are electrically connected in parallel to an external power supply and both of them are subject to protection against corrosion. Overall corrosion is reduced by controlling the surface of the cast iron FC200 to have a current density of 5 to 100 $\mu A/cm^2$. Gap corrosion is reduced by controlling the gap of the stainless steel SUS316L to have a current density of 5 to 100 $\mu A/cm^2$.

Second Embodiment

[0078] A description will hereinafter be given of the case where the corrosion protection system according to the present invention is applied to the pump device 30 shown in Fig. 1. This is the case where the above-described first test equipment 61 is applied to an actual device. As shown in Fig. 2, the surfaces of both of a column pipe 31 serving as a cathode material and a sacrificial anode 3 are brought into contact with seawater. Furthermore, the column pipe 31 and the sacrificial anode 3 are fastened at their portions not in contact with the seawater by an electrically conductive fastener 4, such as a bolt. The sacrificial anode 3 reduces the potential of the column pipe 31 to a lower potential than the immersion potential of the column pipe material itself.

[0079] To control the temperature of the portion of the sacrificial anode 3 in contact with the seawater, a temperature control device 17 is provided which includes a measurement unit 20 attached to the sacrificial anode 3 and a control device 16 disposed on an installation site of a seawater intake pump. The measurement unit 20 includes a heating/cooling unit 11 and a temperature detector 12 and the control device 16 includes a control unit 13 and a power supply 14. A feature of this present embodiment is that the system includes a zero-shunt ammeter 9 (not shown in Fig. 2) configured to measure the current value between electrically conductive portions of the column pipe 31 and the sacrificial anode 3.

[0080] In the seawater intake pump 30, the sacrificial anode 3 is disposed on the outer peripheral surface of the column pipe 31. The sacrificial anode 3 is electrically conductively connected and fastened to the column pipe 31 by the electrically conductive fastener 4. The heating/cooling unit 11 is mounted to the sacrificial anode 3 so that a thermal conduction sheet 10 adhering to the sacrificial anode 3 is interposed between them.

[0081] Furthermore, the temperature detector 12 is attached to a side surface of the sacrificial anode 3. The heating/cooling unit 11 and the temperature detector 12 are connected through cables 15b and 15c, respectively, to the control unit 13. The cables 15b and 15c have the function of transferring signals and the function of supplying electric power. The control unit 13 is connected through a cable 15a to the power supply 14. A collection of the heating/cooling unit 11, the temperature detector 12, the control unit 13, the power supply 14, and the cables 15a to 15c is generally called a temperature control device 17.

[0082] A sacrificial anode 3 and a measurement unit 20 are also provided on the inside surface of the column pipe 31. In this case, in order to avoid giving any effect on the flow through the pump 30 and prevent the measurement unit 20 together with the sacrificial anode 3 from falling off, a recess is provided in the inside surface of the column pipe 31 and the measurement unit 20 together with the sacrificial anode 3 are disposed in the recess. Furthermore, in order to avoid wasting the space of the recess, the surface of the sacrificial anode 3 is made flush with the inner wall surface of the column pipe 31.

[0083] Alternatively, instead of providing a recess in the inner peripheral surface of the column pipe 31, an opening is created into the column pipe 31. Then, a flange may be provided at this opening and integrated with the measurement unit 20. In this case, the column pipe 31, the flange, and the sacrificial anode 3 are made electrically conductive. An externally powered corrosion protection may be employed in which a pair of electrodes are provided on the outer and inner peripheral surfaces of the column pipe 31 and a voltage is applied to the column pipe 31 and between the electrodes.

In this case, the column pipe 31 is insulated from the electrodes.

[0084] Although the present invention has thus far been described, the present invention is not intended to be limited to the above-described embodiments and various modifications can be made without departing from the spirit of the present invention as defined in the claims.

Reference Signs List

[0085]

1 ... simulated member to be protected against corrosion (simulated pipe member),
3...sacrificial anode,
4...electrically conductive fastener,
5...seawater,
6...artificial seawater,
7...water, 8...water bath,
9... zero-shunt ammeter,
10...thermal conduction sheet,
11...heating/cooling unit,
12, 12a, 12b...temperature detector,
13...control unit,
14...power supply,
15a to 15f...cable,
16...control device,
17...temperature control device,
20...measurement unit,
21...vessel,
30...seawater intake pump (pump device),
31...column pipe,
32...guide vane,
33...impeller casing,
34...suction bell mouth,
35...flange,
36...rotary shaft,
37...guide vane inner wall,
38...impeller,
39...installation unit,
40...shore,
41...conduit,
42...intake tank,
42a...base plate,
43...discharge pipe,
44...dual filter,
45...filtered seawater tank,
46...pump,
47...protective filter,
48...pipe,
49...high-pressure pump,
50...power recovery turbine,
51...pipe,
52...RO membrane module,
53...pipe,
54...product water tank,
55...concentrated water pipe,
61...first test equipment,
62...second test equipment,
63...third test equipment,
70...corrosion protection system,
80...desalination system,

100...cathodic polarization curve,
101...anodic polarization curve.

Claims

1. A corrosion protection system comprising :

   a metallic member to be protected against corrosion;
   a sacrificial anode electrically conductively attached to the metallic member and capable of being controlled in temperature; and
   a temperature control unit configured to control the temperature of the sacrificial anode,

   wherein the metallic member to be protected against corrosion and the sacrificial anode are disposed in an electrolyte.

2. The corrosion protection system according to claim 1, wherein the sacrificial anode includes a heating/cooling unit configured to at least heat or cool the sacrificial anode, a first temperature detector configured to measure the temperature of the sacrificial anode is attached to the sacrificial anode, and the temperature control device is configured to control, based on the temperature measured by the first temperature detector, the temperature of the sacrificial anode using the heating/cooling unit which the sacrificial anode includes.

3. The corrosion protection system according to claim 1, wherein the sacrificial anode includes a heating/cooling unit configured to at least heat or cool the sacrificial anode, a first temperature detector configured to measure the temperature of the sacrificial anode is attached to the sacrificial anode, a second temperature detector configured to measure a temperature of the electrolyte is disposed in the electrolyte, and the temperature control device is configured to control the temperature of the sacrificial anode using the heating/cooling unit so that a difference between the temperatures measured by the first temperature detector and the second temperature detector is in a predetermined range.

4. The corrosion protection system according to claim 1, wherein the sacrificial anode includes a heating/cooling unit configured to at least heat or cool the sacrificial anode, a first temperature detector configured to measure the temperature of the sacrificial anode is attached to the sacrificial anode, a current detector configured to measure a value of current flowing between the sacrificial anode and the metallic member to be protected against corrosion, the temperature control device previously stores a relation between the temperature detected by the first temperature detector and an allowable range of currents detected by the current detector, and the temperature control device is configured to control the heating/cooling unit using a relation between the detected temperature and the detected current so that the current detected by the current detector is in the allowable range.

5. The corrosion protection system according to claim 1, wherein the electrolyte is seawater, a material of the metallic member to be protected against corrosion is stainless steel, a material of the sacrificial anode is zinc alloy, and the temperature of the sacrificial anode is controlled to be more than 30°C and less than 50°C.

6. The corrosion protection system according to claim 2, wherein the electrolyte is seawater, a material of the metallic member to be protected against corrosion is stainless steel, a material of the sacrificial anode is zinc alloy, and the temperature of the sacrificial anode is controlled to be more than 30°C and less than 50°C.

7. The corrosion protection system according to claim 1, wherein the electrolyte is seawater, a material of the metallic member to be protected against corrosion is stainless steel, a material of the sacrificial anode is carbon steel, and the temperature control device is configured to control the temperature of the heating/cooling unit so that the sacrificial anode has a lower temperature than the metallic member.

8. The corrosion protection system according to claim 2, wherein the electrolyte is seawater, a material of the metallic member to be protected against corrosion is stainless steel, a material of the sacrificial anode is carbon steel, and the temperature control device is configured to control the temperature of the heating/cooling unit so that the sacrificial anode has a lower temperature than the metallic member.

9. A pump device including the corrosion protection system according to claim 2, wherein the metallic member to be protected against corrosion is a casing of the pump device and the sacrificial anode is electrically conductively

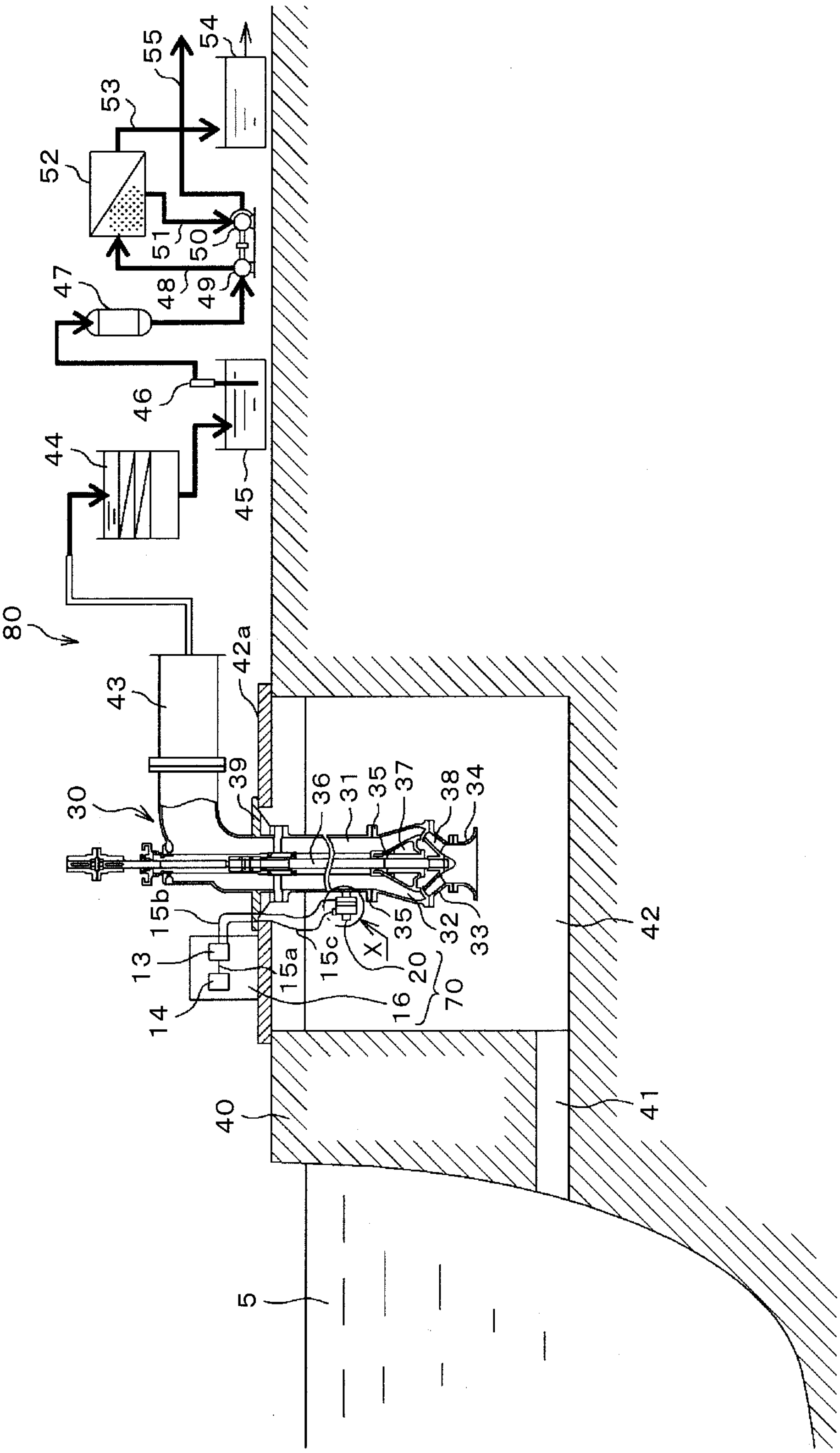
attached to a portion of the casing to be immersed into the electrolyte.

10. A pump device including the corrosion protection system according to claim 3, wherein the metallic member to be protected against corrosion is a casing of the pump device and the sacrificial anode is electrically conductively attached to a portion of the casing to be immersed into the electrolyte.

11. The pump device including the corrosion protection system according to claim 9, wherein the electrolyte is seawater, a material of the casing is stainless steel, a material of the sacrificial anode is zinc alloy, and the temperature control device is configured to control the temperature of the sacrificial anode to be more than 30°C and less than 50°C.

12. The pump device including the corrosion protection system according to claim 9, wherein the electrolyte is seawater, a material of the casing is stainless steel, a material of the sacrificial anode is carbon steel, and the temperature control device is configured to control the temperature of the sacrificial anode so that the sacrificial anode has a lower temperature than the casing.

FIG. 1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36
31
35
37
38
34
15b
13
14
15a
15c
16
20
70
X
35
32
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41
5
44
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46
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50
51
52
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55
54

FIG. 2

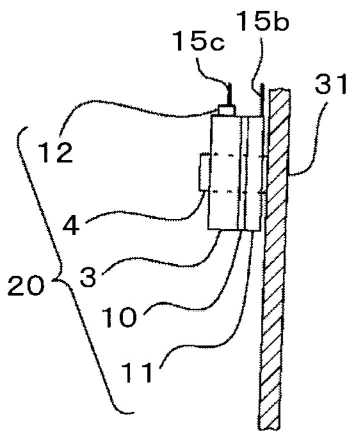

15b
15c
31
12
4
3
20
10
11

FIG. 3

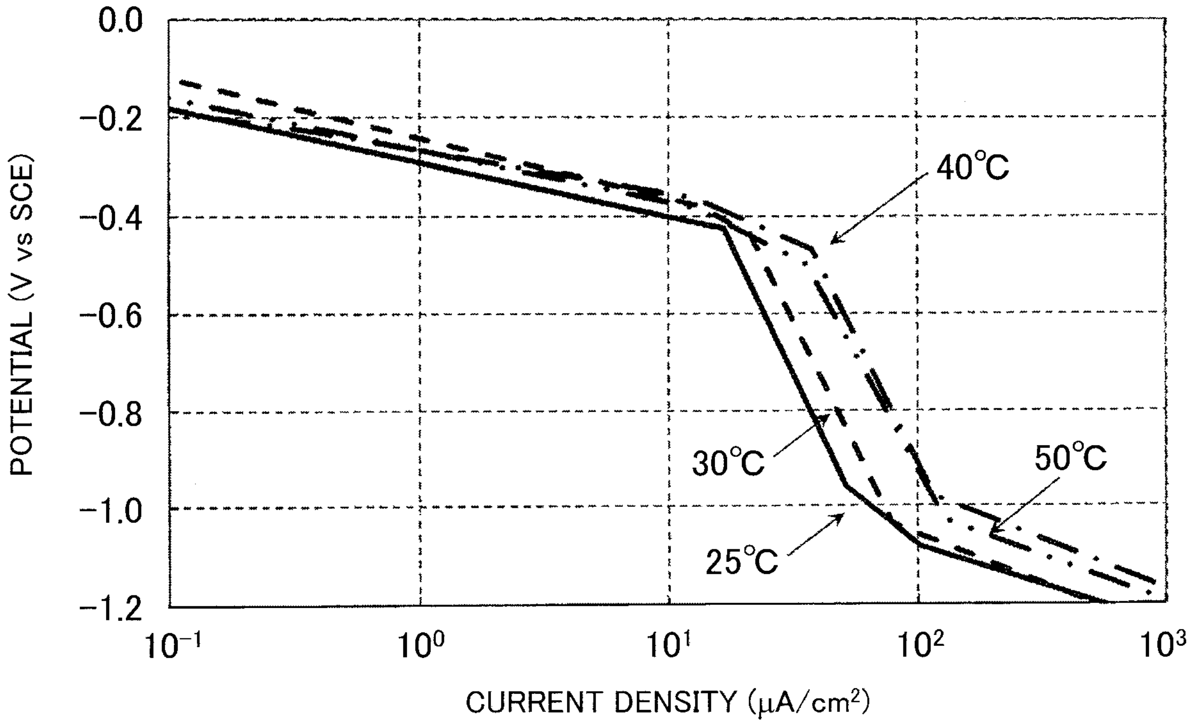
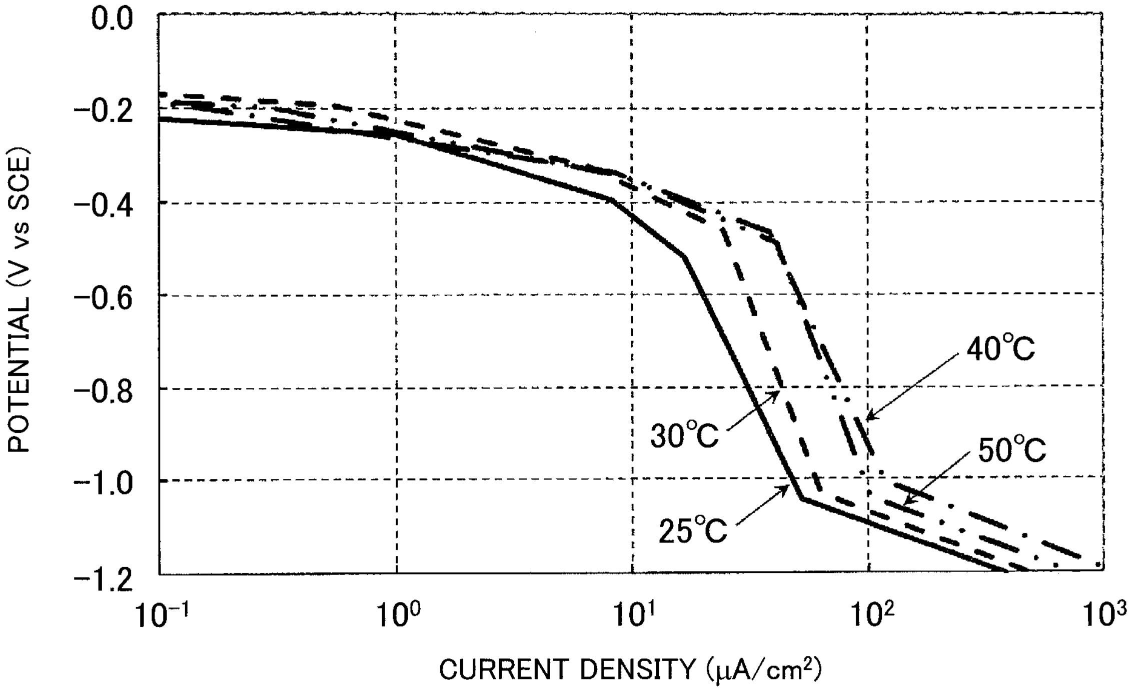
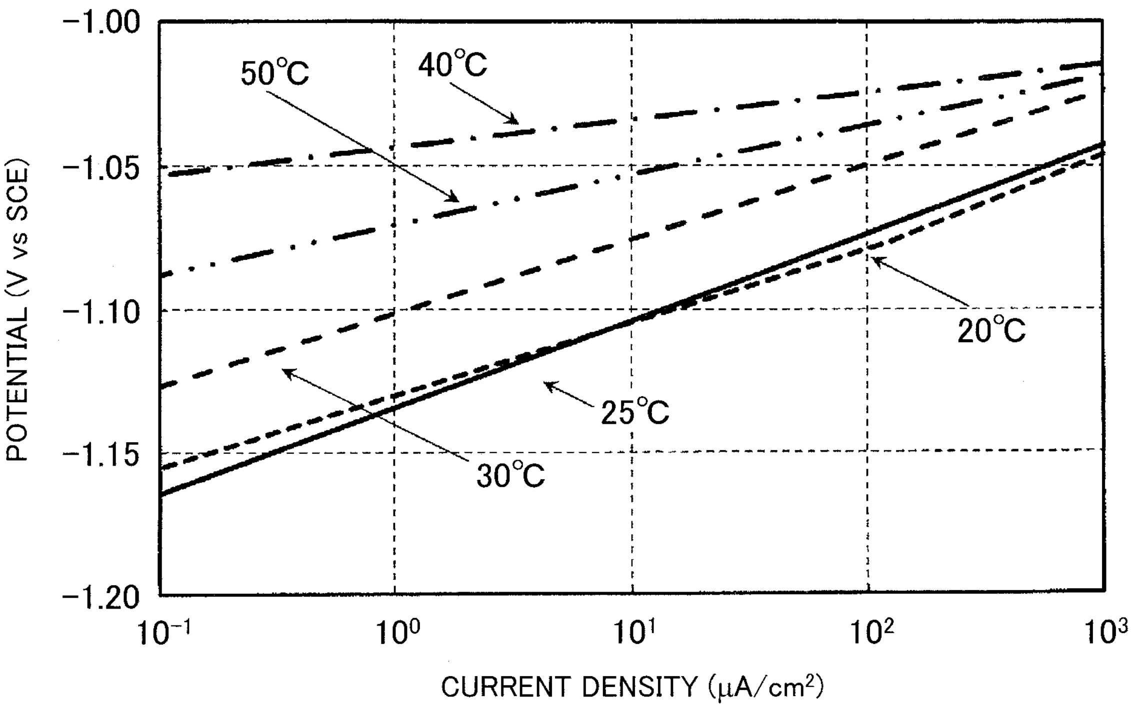

0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
POTENTIAL (V vs SCE)
40°C
30°C
25°C
50°C
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
CURRENT DENSITY (μA/cm²)

FIG. 4



0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
POTENTIAL (V vs SCE)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
CURRENT DENSITY (μA/cm²)
40°C
30°C
50°C
25°C

FIG. 5



−1.00
−1.05
−1.10
−1.15
−1.20
POTENTIAL (V vs SCE)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
CURRENT DENSITY (μA/cm²)
50°C
40°C
20°C
25°C
30°C

FIG. 6

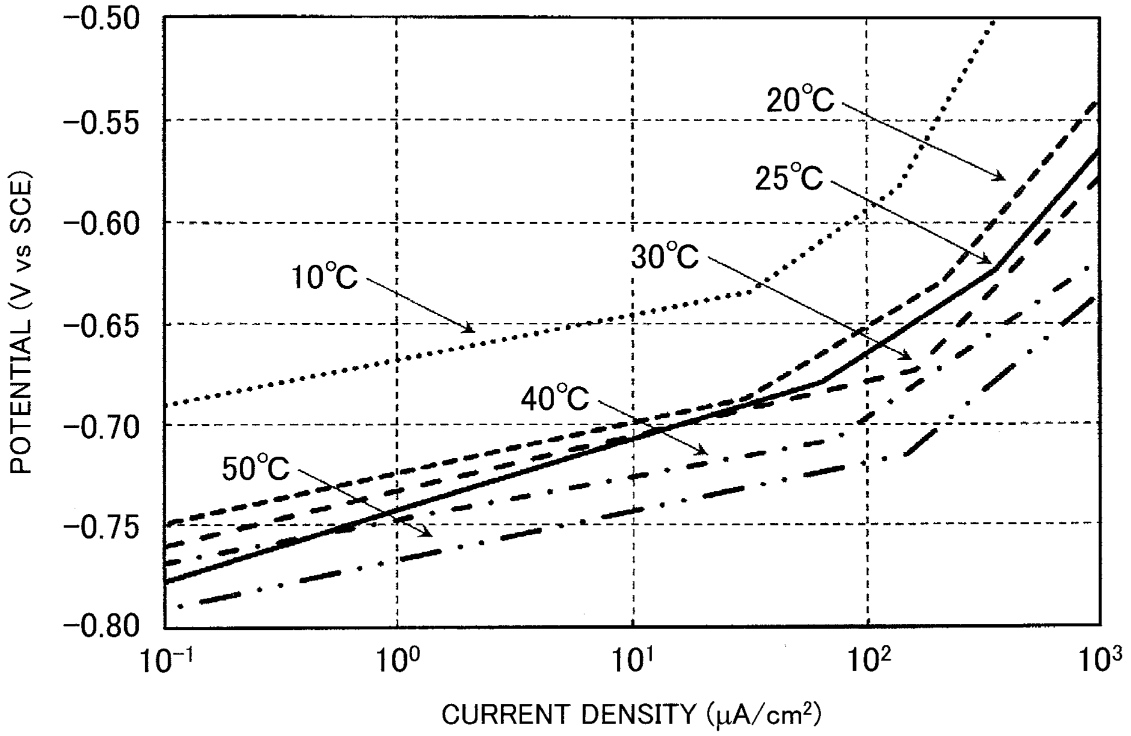

-0.50
-0.55
-0.60
-0.65
-0.70
-0.75
-0.80
POTENTIAL (V vs SCE)
20°C
25°C
30°C
10°C
40°C
50°C
10^{-1}
10^0
10^1
10^2
10^3
CURRENT DENSITY (μA/cm²)

FIG. 7

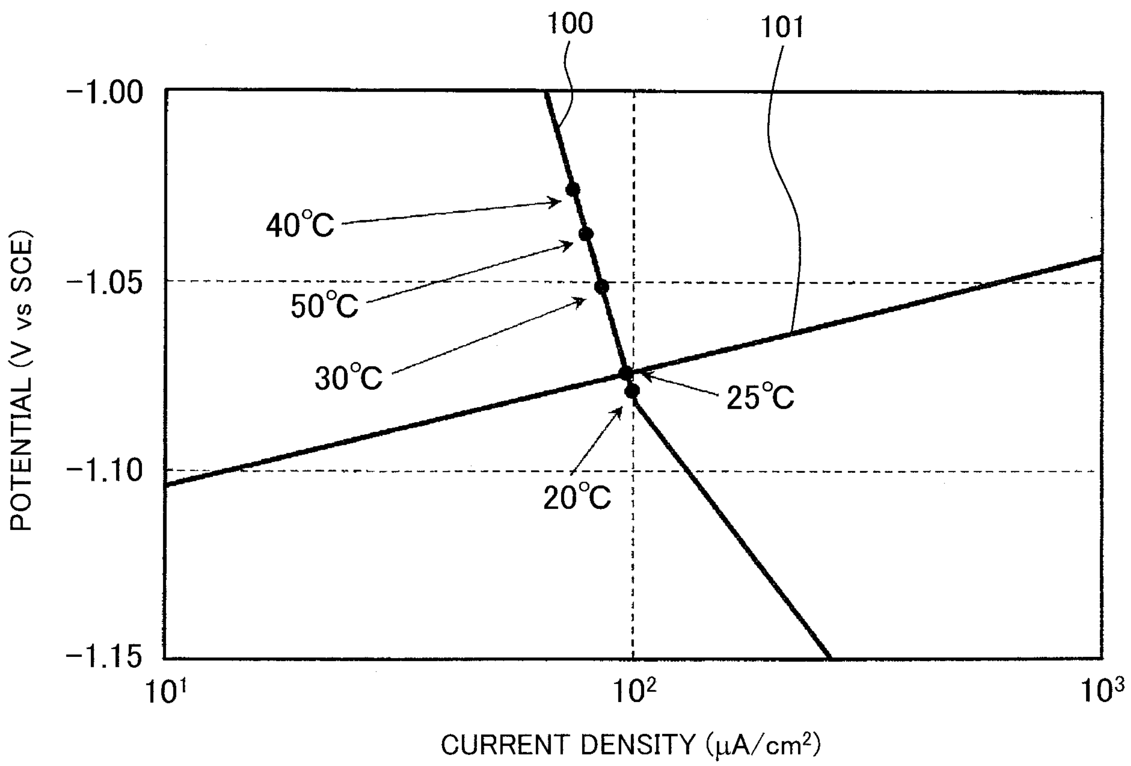

100
101
-1.00
-1.05
-1.10
-1.15
POTENTIAL (V vs SCE)
40°C
50°C
30°C
25°C
20°C
10^1
10^2
10^3
CURRENT DENSITY (μA/cm²)

FIG. 8

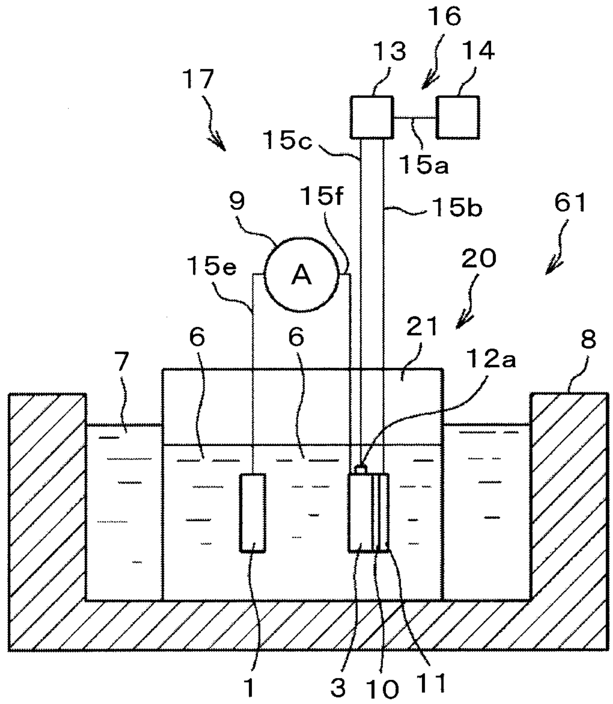

16
13
14
17
15c
15a
9
15f
15b
61
15e
A
20
6
6
21
12a
7
8
1
3
10
11

FIG. 9

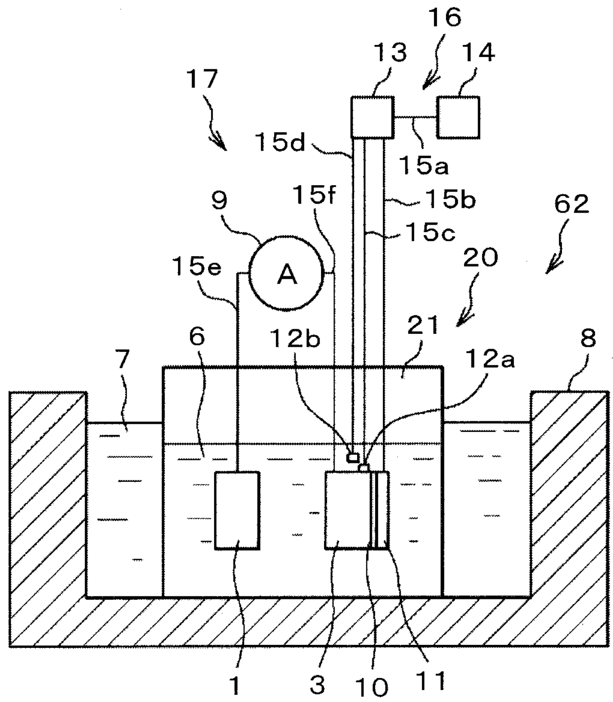

16
13
14
17
15d
15a
9
15f
15b
62
15c
15e
A
20
21
6
12b
12a
7
8
1
3
10
11

FIG. 10

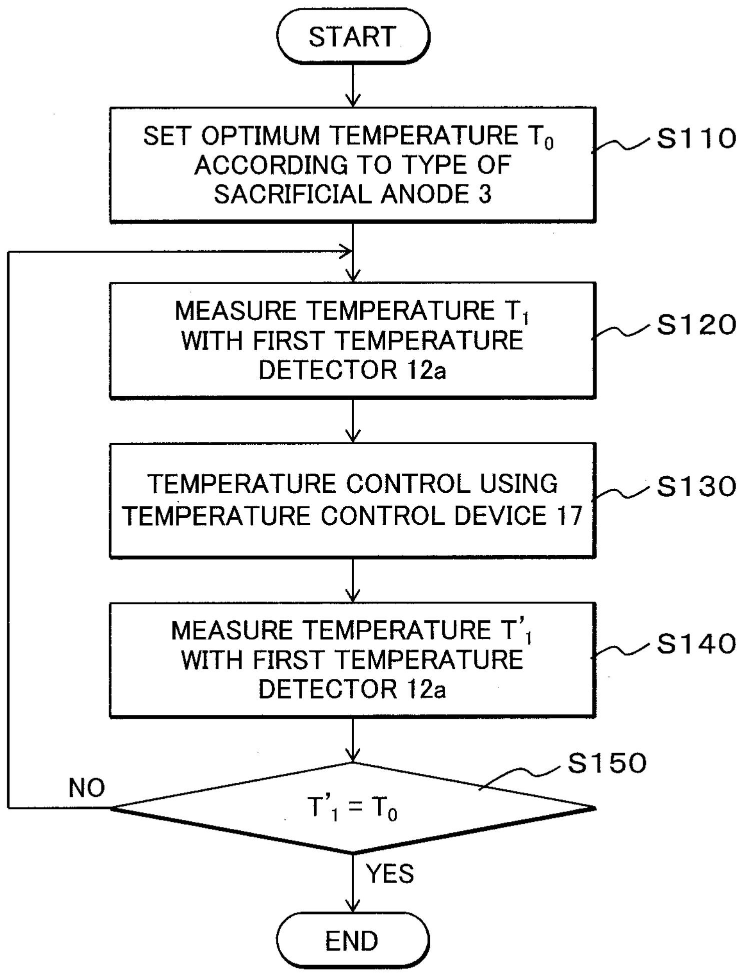

START
SET OPTIMUM TEMPERATURE T_0 ACCORDING TO TYPE OF SACRIFICIAL ANODE 3
S110
MEASURE TEMPERATURE T_1 WITH FIRST TEMPERATURE DETECTOR 12a
S120
TEMPERATURE CONTROL USING TEMPERATURE CONTROL DEVICE 17
S130
MEASURE TEMPERATURE T'_1 WITH FIRST TEMPERATURE DETECTOR 12a
S140
S150
$T'_1 = T_0$
NO
YES
END

FIG. 11

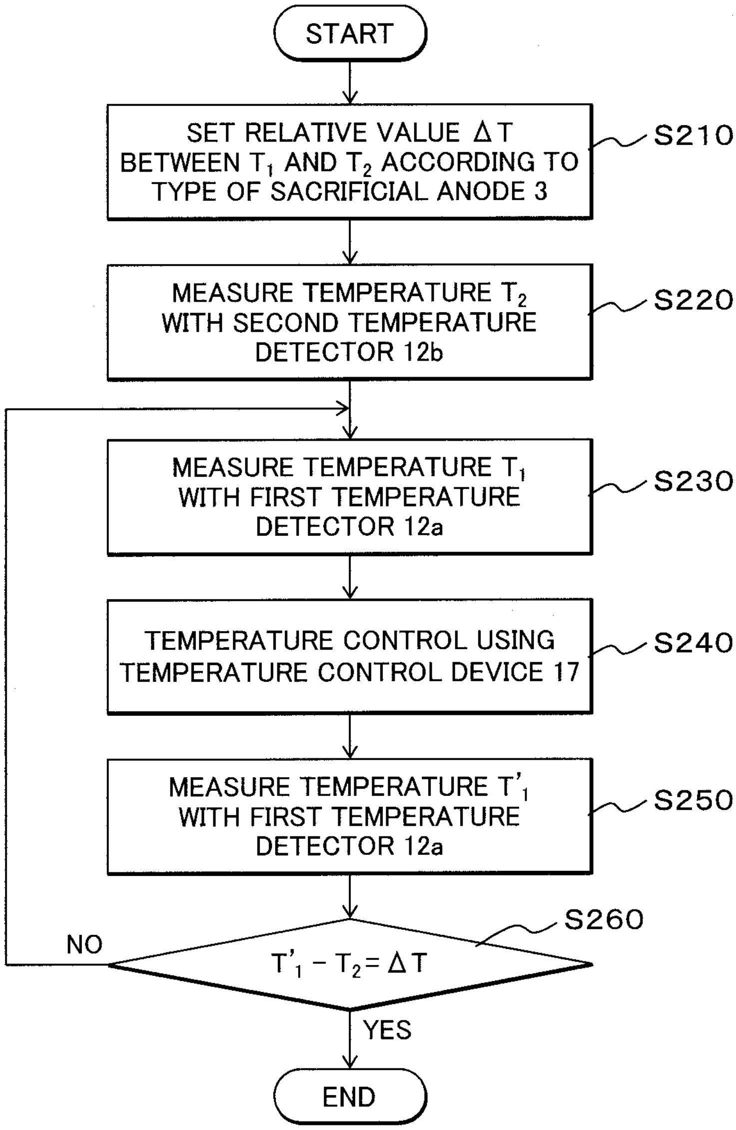

START
SET RELATIVE VALUE ΔT BETWEEN T_1 AND T_2 ACCORDING TO TYPE OF SACRIFICIAL ANODE 3
S210
MEASURE TEMPERATURE T_2 WITH SECOND TEMPERATURE DETECTOR 12b
S220
MEASURE TEMPERATURE T_1 WITH FIRST TEMPERATURE DETECTOR 12a
S230
TEMPERATURE CONTROL USING TEMPERATURE CONTROL DEVICE 17
S240
MEASURE TEMPERATURE T'_1 WITH FIRST TEMPERATURE DETECTOR 12a
S250
S260
NO
$T'_1 - T_2 = \Delta T$
YES
END

FIG. 12

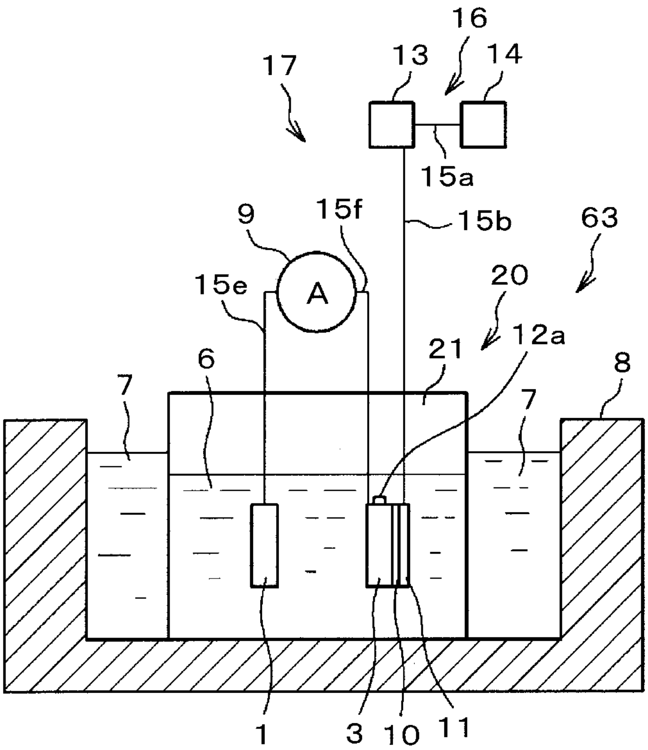
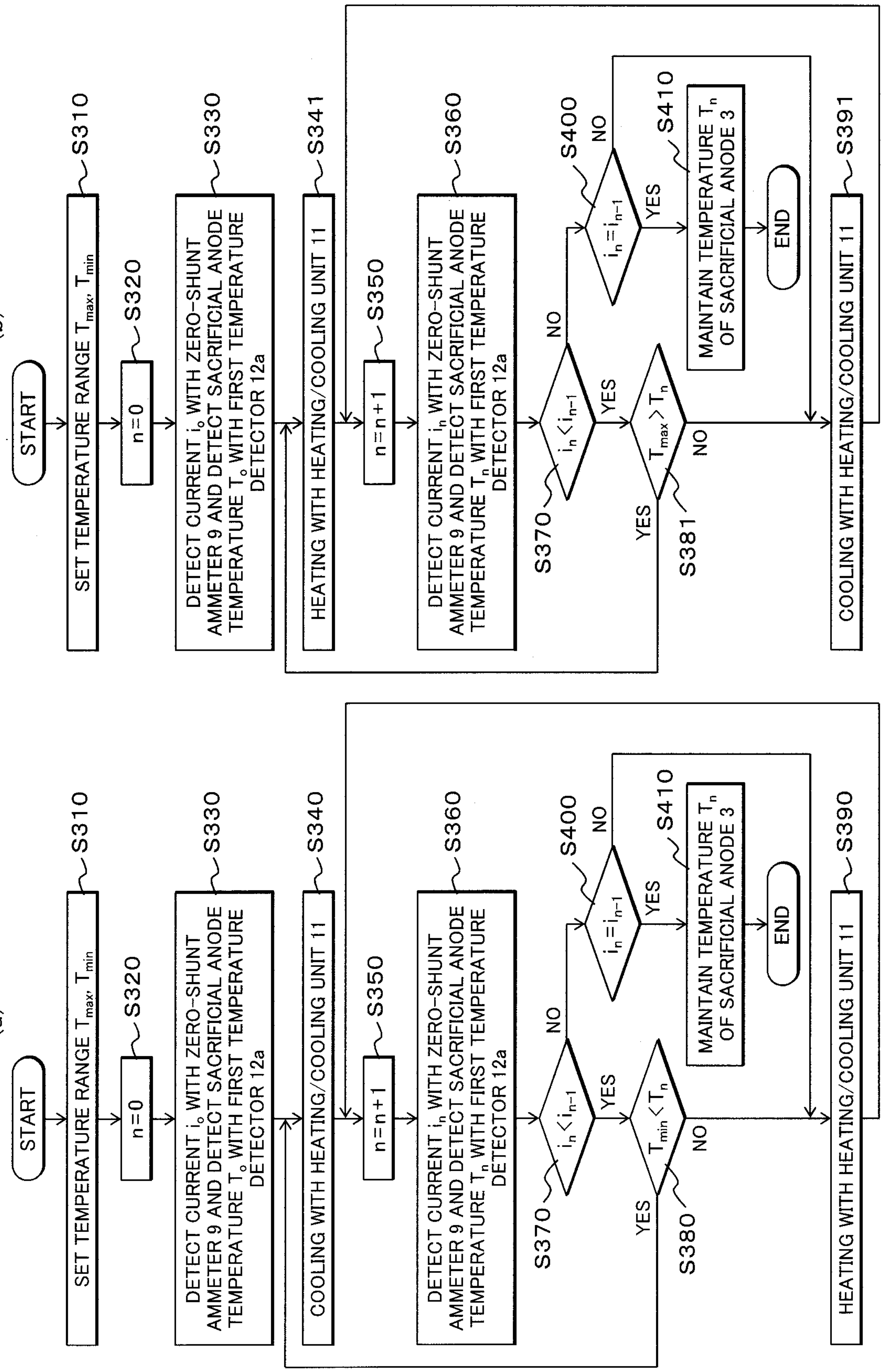


FIG. 13


(a)
START
SET TEMPERATURE RANGE T_{max}, T_{min}
S310
n=0
S320
DETECT CURRENT i_o WITH ZERO-SHUNT AMMETER 9 AND DETECT SACRIFICIAL ANODE TEMPERATURE T_o WITH FIRST TEMPERATURE DETECTOR 12a
S330
COOLING WITH HEATING/COOLING UNIT 11
S340
n=n+1
S350
DETECT CURRENT i_n WITH ZERO-SHUNT AMMETER 9 AND DETECT SACRIFICIAL ANODE TEMPERATURE T_n WITH FIRST TEMPERATURE DETECTOR 12a
S360
$i_n < i_{n-1}$
S370
YES
NO
$T_{min} < T_n$
S380
YES
NO
$i_n = i_{n-1}$
S400
YES
NO
MAINTAIN TEMPERATURE T_n OF SACRIFICIAL ANODE 3
S410
END
HEATING WITH HEATING/COOLING UNIT 11
S390
(b)
START
SET TEMPERATURE RANGE T_{max}, T_{min}
S310
n=0
S320
DETECT CURRENT i_o WITH ZERO-SHUNT AMMETER 9 AND DETECT SACRIFICIAL ANODE TEMPERATURE T_o WITH FIRST TEMPERATURE DETECTOR 12a
S330
HEATING WITH HEATING/COOLING UNIT 11
S341
n=n+1
S350
DETECT CURRENT i_n WITH ZERO-SHUNT AMMETER 9 AND DETECT SACRIFICIAL ANODE TEMPERATURE T_n WITH FIRST TEMPERATURE DETECTOR 12a
S360
$i_n < i_{n-1}$
S370
YES
NO
$T_{max} > T_n$
S381
YES
NO
$i_n = i_{n-1}$
S400
YES
NO
MAINTAIN TEMPERATURE T_n OF SACRIFICIAL ANODE 3
S410
END
COOLING WITH HEATING/COOLING UNIT 11
S391

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/069869

A. CLASSIFICATION OF SUBJECT MATTER
C23F13/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C23F13/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2014
Kokai Jitsuyo Shinan Koho	1971-2014	Toroku Jitsuyo Shinan Koho	1994-2014

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2003-34886 A (Hitachi, Ltd.), 07 February 2003 (07.02.2003), entire text (Family: none)	1-12
A	JP 2000-273566 A (Nippon Corrosion Engineering Co., Ltd.), 03 October 2000 (03.10.2000), entire text (Family: none)	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 September, 2014 (03.09.14)	16 September, 2014 (16.09.14)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

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Patent documents cited in the description

- JP 2005194624 A **[0004]**
- JP 2003034886 A **[0004]**
- JP HEI10306388 A **[0004]**