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Cathodic protection apparatus in systems for the circulation of corrosive liquids.

In a shell-and-tube heat exchanger having titanium-material tube sheets (4) and tubes (3) and a pair of steel chambers (2) and adjoining steel piping (1) at each end, corrosion of the steel parts and hydrogen embrittlement of the titanium-material parts are prevented by an apparatus comprising: an electrically insulative lining (8) covering the entire inner wall surface of each chamber (2) and that of a specific region (l_2) of the contiguously adjoining piping (1); and at least one cathodic protection means (9) installed within the piping (1) at a position spaced apart by a specific distance (l_1) from the bottom face of each chamber (2), where the specific distance (l_1) is longer than the length of the specific region (l_2).

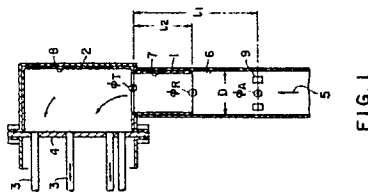


FIG. 1

CATHODIC PROTECTION APPARATUS IN SYSTEMS FOR CIRCULATION OF CORROSION-CAUSING LIQUIDSBACKGROUND OF THE INVENTION

This invention relates generally to cathodic protection in conduit systems conveying corrosion-causing liquids such as sea water and more particularly to a cathodic protection apparatus of titanium heat exchangers in which sea water is used for cooling in electric power generating plants and the like and in water circulating systems connected to these heat exchangers. The term "heat exchanger" as used herein is intended to include all types thereof inclusive of vapor condensers.

Among the heat exchangers of power plants known heretofore, there have been various types in which sea water is used for cooling. In recent power plants, for reasons arising from the importance of improving reliability, so-called titanium heat exchangers, in which titanium is used in the heat exchanging parts such as the heat transmitting tubes and the tube sheets, are being widely utilized in view of the excellent corrosion resistant property of titanium relative to sea water. The water chambers of a titanium heat exchanger are generally formed from carbon steel, but, in order to improve their resistance to corrosion due to sea water, their inner surfaces are covered by a lining of high reliability such as, for example, a rubber lining.

On the other hand, the sea water system piping is made of carbon steel, and its inner surface is covered by a coating such as, for example, a tar-epoxy resin coating. It is also possible to cover the inner surface of this piping with a lining of high reliability, but, in general, the total length of such a piping is long, and moreover, since its nominal or inner diameter is also large, it is not economically feasible to cover its inner surface over its entire length with a lining of high reliability. For this reason, it is not a general practice to provide the piping inner surface with a lining.

Accordingly, corrosion prevention with respect to sea water in heat exchangers of this character and in their piping system has heretofore been carried out in the following manner. The heat transmitting tubes and the tube sheets are made of titanium, while the water chambers are made of carbon steel, and their inner surfaces are covered with a lining of high reliability thereby to prevent galvanic corrosion. Furthermore, since coating is carried out in the sea water system piping, there are cases where a cathodic protection apparatus is not provided in the piping and cases where a cathodic protection apparatus is further provided in the piping in consideration of the possibility of the coating being damaged. However, from the point of view of improving the reliability, a corrosion-prevention device is provided recently in many cases in the piping.

From the point of view of prevention of galvanic corrosion of equipment, the sea water conducting piping of the prior art as described above has been accompanied by the following problems. As is well known, at an electric potential below -600 mV.SCE (saturation calomel electric potential), titanium exhibits a characteristic of undergoing hydrogen embrittlement. For this reason, when titanium is to be used, its potential must be maintained above this potential.

On the other hand, in the case where the coating applied to the inner wall surface of a piping made of carbon steel is damaged, there is a possibility of the carbon steel being damaged by galvanic corrosion due to the difference between the natural potentials of titanium and carbon steel, that is, -150 to +50 mV.SCE of titanium and -460 to -720 mV.SCE of carbon steel. For this reason, it is necessary that the potential of carbon steel piping be -770 mV.SCE or less. Thus, if the conditions of use of both titanium and the carbon steel piping are to be satisfied, a potential region (between -600 and -770 mV.SCE) which cannot be controlled arises in the neighborhood of the connections between the heat exchanger and its piping and gives rise to problems in corrosion prevention design or problems in the reliability of an actual plant.

One example of a heat exchanger in which sea water is used as a cooling medium is a vapor or steam condenser in a power plant. In general, such heat exchangers of the shell-and-tube type are widely used. Since the cooling tubes of such a vapor condenser directly contact sea water, they are made of a metal which is not readily corroded such as, for example, a copper alloy having aluminum brass as the predominant component. Furthermore, for the condenser tube sheets, a metal such as naval brass is used. In general, steel is used for the water chambers and the equipment and piping connected to the condenser. For parts such as wells for thermometers and temperature gauges and other instruments, monel metal and stainless steel are used.

As conducive to a full understanding of the problems relating to the instant art of galvanic corrosion prevention, one example of a known steam condenser of a power plant and equipment, piping, and

instruments relating to this condenser will now be described with reference to FIG. 14 of the accompanying drawings.

Steam 1 discharged from a steam turbine (not shown) is introduced into a steam condenser 2 and contacts the outer surfaces of a plurality of cooling tubes 3 installed between tube shells 22 within the condenser 2 and conducting sea water caused to flow therethrough. The vapor is thus cooled and condensed. The resulting condensate 5 is then pumped out by a condensate pump 4 of the condenser 2 for reuse in the power plant, thus being recovered and fed as feed water to a feed water heater (not shown). In general, aluminum brass is used for the cooling tubes 3 of the condenser 2.

On the other hand, cooling sea water 6 is supplied into the inlet water chamber 8 (hereinafter referred to as chamber) through an inlet circulating water pipe 7 made of carbon steel plate and internally lined with a galvanic corrosion preventive paint of a material such as tar-epoxy resin or a covering material. The sea water thus flows through the inlet chamber 8 and then through the above mentioned cooling tubes 3 made of aluminum brass, absorbing the heat of the steam 1 through the walls of the cooling tubes 3. The temperature of this sea water thus rises, and the sea water flows through the outlet chamber 9 and an outlet circulating water pipe 10 and is discharged into a discharge outlet.

The inlet and outlet circulating water pipes 7 and 10 are generally provided respectively with butterfly valves 11 for shutting off, changing over, and other operations with respect to the cooling sea water 6 and also with instruments such as a temperature gauge 12 (temperature detecting seat) and a pressure gauge 13 (pressure detecting seat) for detecting or monitoring conditions such as temperature and pressure. Furthermore, a ball scouring system for maintaining the cleanliness of inner surfaces of the cooling tubes 3 is installed in the sea water circulation system.

This ball scouring system is essentially a circulatory system for sending cleansing balls through the cooling tubes 3 and comprises: a ball collector 14 installed within the outlet circulating water pipe 10 and operating to collect and recover cleansing balls within the cooling sea water 6 being discharged; a ball circulating pipe 15 through which the balls thus recovered are conducted out of the pipe 10; a ball circulating pump 16 to which the balls are thus conducted; a ball recovering device 17 for recovering the balls from the pump 16; and a ball feeding pipe 18 for feeding the balls thus recovered again into the cooling sea water flowing through the inlet circulating water pipe 7. By repeating this circulatory operation, contaminants such as foreign matter adhering to the inner surfaces of the cooling tubes 3 are removed and washed away by the cooling sea water.

Flexible expansion joints 19 made of rubber are connected respectively between the inlet circulating water pipe 7 and the inlet chamber 8 and between the outlet chamber 9 and the outlet circulating water pipe 10 for the purpose of absorbing installation errors and minute displacements at the time of operation.

For removing air from the inlet and outlet chambers 8 and 9, air vent pipes 20 provided with air vent valves 21 are respectively connected to the upper parts of these chambers 8 and 9.

In order to prevent galvanic corrosion due to sea water of the parts of the condenser and the circulating water pipes contacted by the sea water, great care is exercised in the design of these parts with consideration of the selection of their materials and protection of their exposed metal surfaces by coating or covering with a galvanic corrosion preventive material. In general, the corrosion phenomenon is of two kinds, namely, natural corrosion in which a single metal in an acidic or oxidizing environment corrodes and galvanic corrosion (or electrolytic corrosion) occurring when metals of different kinds are in mutual contact. Since this electrolytic corrosion proceeds at an extremely rapid rate, it requires special attention. This term "electrolytic corrosion" ordinarily refers to the phenomenon wherein, when electrically connected metals of different kinds are placed in an electrolytic solution, a natural potential difference is established with the noble metal as the cathode and the base metal as the anode, and the cathode metal assumes the form of metal ions and is eluted into the electrolytic solution, while the base metal is corroded.

The natural potentials of various metals in sea water are indicated in FIG. 15. Among the seven kinds of metals whose natural potentials are shown here, titanium (Ti) is the furthest toward the noble side, while zinc (Zn) is furthest toward the base side. For example, in the case where brass on the noble side and iron on the base side are immersed in and contacting sea water and are mutually in electrical contact, the natural potential difference V between these two metals cause the iron on the base side to be subjected to electrolytic corrosion. Also in the case where stainless steel (passive state) on the noble side and iron on the base side are in contact and connected electrically in sea water, the iron on the base side undergoes electrolytic corrosion due to the natural potential difference V between the two metals. The same phenomenon occurs with combinations of other metals. The greater the natural potential difference between the two metals, the greater is the electrolytic corrosion action. In FIG. 15, the unit of electric potential of the horizontal axis (abscissa) is volts saturated calomel electric potential ($V \cdot SEC$).

It is possible for these phenomena to occur also in the sea water system of a power plant. For example,

there are possibilities of electrolytic corrosion occurring between exposed metals of the cooling tubes, strainer, valves, and instrument fittings such as wells of temperature gauges used in a heat exchanger. Furthermore, in addition to the above possibilities, the following cases are conceivable. The inner wall steel surfaces of piping equipment are covered by a corrosion preventive paint or a coating material so as to prevent their being contacted by sea water and thereby corroding. However, in the case where, for some reason, the paint coating or covering is damaged whereby the steel surfaces are exposed to sea water and the noble metal material and the base metal steel surface are electrically connected, the natural potential difference between these two metals causes electrolytic corrosion of the steel surfaces on the base side. As shown in FIG. 16, for example, in the case where aluminum brass is used for the cooling tubes 3 of the steam condenser 2, and naval brass is used for the condenser tube sheets 22, since the walls of the inlet and outlet chambers 8 and 9 and the inlet and outlet circulating water pipes 7 and 10 are ordinarily made of steel plate, the steel plate becomes the metal on the base side.

If the protective coating or covering layer on the inner surfaces of the above described chambers 8 and 9 and the circulating water pipes 7 and 10 is defective because of improper application or has been damaged by a cause such as flow of the water, and the steel surfaces under this defective coating become exposed to the sea water, the natural potential difference between the brass and the iron will cause the steel surfaces, of the base metal iron, to undergo electrolytic corrosion.

This phenomenon will now be described more fully with respect to the outlet chamber 9, the outlet circulating water pipe 10, and parts related thereto of a vapor condenser 2 and with reference to FIG. 16 and succeeding figures.

As a supposition, it will be assumed that a breakage 23a exists in the protective inner lining of the outlet chamber 9 of the condenser 2, and a breakage 23b exists also in the inner lining of the outlet circulating water pipe 10. Consequently, the steel surfaces underlying the breakages 23a and 23b are exposed to the cooling sea water 6. Here, it will also be assumed that the condenser 2 is grounded 25 by way of a structure such as its foundation, and also that the outlet circulating water pipe 10 is also grounded 25 via a connected part such as supports of the piping or pipes buried in the ground. Thus, an electrical circuit is formed from the exposed steel underneath the breakages 23a and 23b, via the cooling sea water 6, through the tube sheet 22 and the cooling tubes 3, and through the shell of the condenser 2. Consequently, electrolytic corroding currents 24a and 24b flow from the exposed steel at the breakages 23a and 23b to the tube sheet 22 and the cooling tubes 3, whereby the exposed steel parts at the breakages are corroded. It will be apparent that this phenomenon will occur in the same manner under similar conditions also in the inlet chamber 8 and the inlet circulating water pipe 7.

This phenomenon has been described above with respect to the case where the cooling tubes 3 and the tube sheet 22 are made of a noble metal. However, in the case where parts such as the ball collector 14 and the ball feeding pipe 18 of the ball scouring system as described hereinbefore and illustrated in FIG. 14, the butterfly valves 11, the sensor parts of the temperature gauges 12 and the pressure gauge 13, and the like are composed of a metal such as stainless steel which is more noble than iron, a natural potential difference arises between these nobler metal parts and the iron surfaces exposed by the breakages 23a and 23b, whereby the base metal iron surfaces undergo corrosion similarly as described above.

This phenomenon will also be described in detail with reference to FIG. 17. In the outlet circulating pipe 10 of the condenser 2 shown in FIG. 17 is installed a ball collector 14 which is made of a material such as stainless steel, and to which a ball recirculating pipe 15 is connected. Here, it will be assumed that breakages 23a and 23b have occurred similarly as described above in conjunction with FIG. 16. Consequently, in addition to the electrolytic corrosion current 24b flowing from the exposed steel at the breakage 23b of the outlet circulating water pipe 10 to the tube sheet 22 and the cooling tubes 3, an electrical circuit is formed from the exposed metal at the breakage 23b, through the cooling sea water 6, and through the ball collector 14, whereby an electrolytic corrosion current 24c flows from the exposed metal at the breakage 23b to the ball collector 14. In this case also, the exposed metal at the breakage 23b corrodes.

In the case where the breakage 23b is near the condenser 2, the tube sheet 22 and the cooling tubes 3 have an effect on the occurrence of this phenomenon, while in the case where the breakage 23b is near the ball collector 14, this ball collector 14 has an effect. In this connection, the stainless steel referred to here is stainless steel having a stable passive-state film, and the potential of stainless steel (passive state) as indicated in FIG. 15 is ordinarily of the order of 0 to 100 mV·SCE. However, if the thickness of this passive-state film is ample, brass becomes baser than the stainless steel (passive state).

Therefore, as long as some abnormal condition does not occur, stainless steel (passive state) will not corrode. However, in the case where the operational conditions of the condenser 2 change and assume a special state, for example, a state wherein a portion of the stainless steel surface becomes active because

of foreign matter in the sea water, the stainless steel becomes the base side. Consequently, a natural potential difference arises between the naval brass of the tube sheet 22 and the aluminum brass of the cooling tubes 3, in which case the stainless steel corrodes.

5 The phenomenon will now be described with reference to FIG. 18. In this example, it may be considered that one portion of the ball collector 14 installed in the outlet circulating water pipe 10 assumes an active state, while the other parts are covered by a passive state film. Then, it will be assumed as a supposition that, at this time, the region in which the active state has appeared is the area designated by the reference character A in FIG. 18.

10 The electrical circuit in this case is that from the outlet circulating pipe 10 to the ball collector 14 of exposed stainless steel through the cooling sea water 6, the condenser tube sheet 22 and the cooling tubes 3, and the shell of the condenser 2. Consequently, an electrolytic corrosion current 24 flows from the portion of exposed ball collector 14 covered by the passive state film, through the region A of the ball collector 14, to the tube sheet 22 and the cooling tubes 3. In this case also, the ball collector 14 of stainless steel undergoes electrolytic corrosion with the region A as the center thereof.

15 As a method of protecting equipment from the electrolytic corrosion phenomenon as described above in the inlet and outlet chambers 8 and 9 and the inlet and outlet circulating water pipes 7 and 10, the measure of causing a galvanic corrosion preventive electric current to flow in the input and output chambers 8 and 9 is being widely used. With respect to a similar phenomenon in the ball collector 14 and like parts, also, the measure of passing a suitable galvanic corrosion preventive current in the neighborhood of such parts thereby to prevent electrolytic corrosion is being practiced.

20 FIG. 19 indicates a mode of practice of electrical corrosion prevention in an all-titanium vapor condenser on the basis of the foregoing considerations. In the arrangement shown in FIG. 19, an external power supply electrode 36 is installed in the outlet circulating water pipe 10 and is connected to an electrical corrosion prevention device 38 for generating corrosion prevention electric current 37. At the lower part of the outlet chamber 9 and at the end of the outlet pipe 10 nearest the condenser 2 are respectively provided reference electrodes 39a and 39b for controlling the corrosion prevention potential and the current value. These reference electrodes 39a and 39b are respectively coupled by way of potential control devices 40a and 40b to the electrical corrosion prevention device 38. The metal structure of the outlet pipe 10 is grounded as indicated at 41. Although not shown in FIG. 21, equivalent items of equipment are provided also with respect to the inlet pipe 7 and chamber 8 on the inlet side of the condenser 2 to provide the same effect of corrosion prevention.

In addition, an external power supply electrode 31 is installed in the outlet circulating water pipe 10, and an electrical corrosion prevention device 33 is connected to this electrode 31. Furthermore, at a position in the vicinity of a ball collector 14 within the outlet pipe 10 is installed a reference electrode 34 for controlling the corrosion prevention potential and electric current value. This reference electrode 34 is connected via a potential control device 35 to the electrical corrosion prevention device 33.

35 In the above described arrangement, the corrosion prevention electric current 37 flows from the external power supply electrode 36 toward the tube sheet 22, the cooling tubes 3, and parts 23a and 23b where the lining has been damaged, and corroding current 24 (FIG. 16) flowing from these lining-damaged parts 23a and 23b is nullified. The reference electrode 39a detects the potential at the lower part of the outlet chamber 9 and transmits a corresponding detection signal to the electrical corrosion prevention device 38. The set potential in this case is selected to be on the nobler side relative to $-600 \text{ mV} \cdot \text{SCE}$ in order to avoid the occurrence of hydrogen embrittlement of the titanium material.

40 The reference electrode 39a detects the potential in the vicinity of the outlet of the outlet pipe 10 and transmits the corresponding detection signal to the corrosion prevention device 38. The set potential in this case is set at a value of the order of -650 to $-900 \text{ mV} \cdot \text{SCE}$ with respect to iron.

45 As set forth above, in all all-titanium vapor condenser, in order to prevent electrolytic corrosion of the exposed steel surfaces of lining-damaged parts 23a and 23b, for example, as shown in FIG. 19, which have occurred in the outlet chamber 9 and the outlet pipe 10, an external power supply electrode 36 is provided in the outlet pipe 10, and, from this electrode 36, a corrosion preventive electric current 37 is caused to flow toward, for example, the damaged part 23a existing in the outlet chamber 9.

50 In this case, however, if the electrode 36 is positioned too close to the side of the outlet chamber 9, the corrosion preventive current 37 will tend to flow also into the tube sheet 22 and the cooling tubes 3 at the same time it flows to the lining-damaged part 23a. When this loss current thus flows into the tube sheet 22 and the cooling tubes 3, the polarization characteristic of the titanium material fluctuates according to the magnitude of the current value, whereby the titanium material exhibits a potential on the baser side relative to the natural potential it exhibits in sea water.

55 For this reason, the potential which the reference electrode 39a detects at the lower part of the outlet

chamber 9 is on the baser side of approximately $-600 \text{ mV} \cdot \text{SCE}$, the potential causing hydrogen embrittlement of the titanium material. The feedback signal from this reference electrode 39a is transmitted to a potential control device 40a, and the corrosion prevention potential of the corrosion prevention device 38 is thus controlled to be a value on the nobler side. The corrosion preventive current 37 outputted from the external power supply electrode 36 is thereby restricted.

At this time, however, as a result of the corrosion prevention potential being restricted on the nobler side, it departs from -650 to $-900 \text{ mV} \cdot \text{SCE}$, which is the corrosion prevention potential of iron, whereby electrolytic corrosion of the lining-damaged part 23a of the outlet chamber 9 can no longer be prevented. Similarly, it becomes difficult to stop the electrolytic corrosion of the lining-damaged part 23b of the outlet pipe 10 near the outlet chamber 9.

One measure for overcoming this difficulty may appear to be the provision of the external power supply electrode 36 at a position far apart from the outlet chamber 9. In this case, the loss current flowing through the tube sheet 22 and the cooling tubes 3 becomes much smaller than that in the aforescribed case, and the detected potential of the reference electrode 39a becomes nobler than the above mentioned approximately $-600 \text{ mV} \cdot \text{SCE}$, whereby hydrogen embrittlement of the titanium material does not occur. However, this assumption of the detection potential of a nobler value, as considered in view of the entire interior of the outlet chamber 9, means that it will assume a potential which is further on the nobler side at a position remote from the reference electrode 39a.

Then, if it is possible, as a supposition, to separate the external power supply electrode 36 far from the outlet chamber 9 and, at the same time, to set the corrosion prevention potential of iron of -650 to $-900 \text{ mV} \cdot \text{SCE}$ further on the baser side, the countermeasure is relatively easy and may be considered desirable.

However, in the case where this measure is taken in the vicinity of the output pipe 10 wherein the electrode 36 is mounted, there is concern that problems such as the following may arise, whereby there is no possibility of it being used in actual practice. That is, the surface of the covering material such as rubber or tar-epoxy resin lining the steel surface for corrosion prevention of the outlet pipe 10 and other parts tend to undergo an acceleration of deterioration caused by the increase in the corrosion prevention potential and the current value due to this measure. As a consequence, there is the risk of these materials peeling off from the steel surface, which becomes a great problem.

Thus, merely bringing the corrosion prevention potential of iron of -650 to $-900 \text{ mV} \cdot \text{SCE}$ further to the baser side is not desirable since it has a deleterious effect on the lining material side.

On the other hand, the conventional electrical corrosion prevention method lacking careful consideration necessary for the positioning of external power supply electrode 36 and other conditions, as described hereinbefore, cannot be said to be fully useful for true electrical corrosion prevention, and therefore there is a need for improvement.

SUMMARY OF THE INVENTION

In view of the above described circumstances in the prior art, it is an object of this invention, in a general aspect thereof, to provide, in a heat exchanger and interconnected piping thereof, a cathodic protection apparatus wherein a sacrificial anode or external power supply electrodes are installed in the piping at an appropriate distance from the heat exchanger, and, moreover, a lining of high electrically insulative property is provided on the inner wall surface of the piping over a region in the vicinity of the heat exchanger, or, instead of a lining, insulative piping is used thereby to attain full corrosion prevention of the heat exchanger and the piping system thereof.

More specifically, according to this invention, the mounting position of the sacrificial anode or the external power supply electrode is so determined, from the values of the potential and current of this anode or electrode, the conductivity of the sea water, and the inner diameter of the piping, that is set at a potential capable of preventing hydrogen embrittlement of the titanium. Furthermore, while a material of high insulativeness is used for the piping in the proximity of the heat exchanger, the relationship between the scope thereof and the mounting position of the sacrificial anode or the external power supply electrode is determined unconditionally, irrespective of the current flowing from the anode or electrode, the conductivity of the sea water, and the inner diameter of the piping, which were conventionally considered.

It is an object of this invention in another aspect thereof to provide a cathodic protection apparatus for an all-titanium heat exchanger by which method hydrogen embrittlement of the titanium material used in the heat exchanger is suppressed, while, in parts of carbon steel used together with the titanium material, also, corrosion of the steel surface due to electrolytic erosion is positively prevented.

According to this invention in one aspect thereof, briefly summarized, there is provided a cathodic protection apparatus for preventing galvanic corrosion in a sea water circulation system of an all-titanium heat exchanger having a shell, a pair of titanium-material tube sheets closing opposite ends of said shell, a plurality of titanium-material heat transfer tubes supported by and extending through and between said tube sheets, and a pair of chambers connected to the ends of said shell, said chambers being connected to opposite piping of a sea water circulation system, said chambers and said piping made of a metal material which is electrically baser than said titanium material, the inner wall surface of each chamber in entirety being covered with a lining of a substantially strong electrically insulative material, which apparatus comprises: an electrically insulative material provided as a lining on the inner wall surface of said piping in a specific region thereof contiguously from a bottom face of each chamber, and at least one cathodic protection means installed within said piping at a position spaced apart by a specific distance from the bottom face of each chamber which said specific distance is longer than the length of said specific region.

The nature, utility, and further features of this invention will be more clearly apparent from the following detailed description with respect to preferred embodiments of the invention when read in conjunction with the accompanying drawings, briefly described below.

BRIEF DESCRIPTION OF THE DRAWING

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In the accompanying drawings:

FIG. 1 is a side view in section showing the essential organization of one example of the cathodic protection apparatus according to this invention in a sea water circulation system of a heat exchanger;

FIG. 2 is a side view showing lines of equal potential indicating an example of potential distribution in a sea water circulation system in which sacrificial anodes are used for corrosion prevention;

FIG. 3 is a side view similar to FIG. 1 showing another example of the cathodic protection apparatus of the invention;

FIG. 4 is a schematic side view combined with a circuit diagram showing an example of a sea water circulation system of a heat exchanger in which the cathodic protection apparatus of the invention is applied;

FIG. 5 is a side view of the sea water circulation system combined with a graph indicating the state of distribution of potential in the system in which the cathodic protection apparatus of the invention is applied;

FIG. 6 is a graph indicating variations of potential with distance from an electrode at the lower part of the chamber in the example shown in FIG. 1;

FIG. 7 is a graph indicating variation of electric current with position in the same example;

FIG. 8 is a graph indicating states of distribution of potential within an outlet pipe;

FIG. 9 is a schematic side view combined with a circuit diagram of another example of a sea water circulation system in which the method of the invention is applied;

FIG. 10 is a graph indicating variations of potential at the lower part of the outlet chamber of the example illustrated in FIG. 9;

FIG. 11 is a graph indicating variation of current with distance of the same example;

FIG. 12 is a graph indicating the state of distribution of potential within the outlet pipe of the same example;

FIG. 13 is a schematic side view combined with a circuit diagram showing a different example of the invention;

FIG. 14 is a side view, with parts shown in section, showing a vapor condenser of the prior art and its piping system;

FIG. 15 is a diagram indicating the natural potentials of various metals in sea water;

FIGS. 16, 17, and 18 are side views, each of one end of a heat exchanger and its chamber and outlet pipe respectively indicating modes of the electrolytic erosion phenomenon;

FIG. 19 is like a side view showing an example of a cathodic protection apparatus in vapor condensers of the prior art.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The cathodic protection apparatus of a circulating water system using sea water according to this invention functions as will now be described with reference to FIGS. 1 and 2. Electric current flowing out from sacrificial anodes 9 passes through a circulating water pipe 1 and a chamber 2 of a heat exchanger and through a tube sheet 4 and heat transmission tubes 3. In this case, the distribution of the potential within the circulating water pipe 1 in its axial direction indicates a potential which is proportional to the distance in the axial direction of the pipe 1 from the sacrificial anodes 9 according to experiments and analyses as indicated by one example in FIG. 2. It was thus verified that, as the distance away from the sacrificial anodes increases, the absolute value of the potential decreases. This means that Ohm's law can be applied to the potential in the axial direction within the circulating water pipe 1. Accordingly, the following equations are valid. Here, the inner diameter of the circulating water pipe is designated by the reference character D.

$$\phi_T - \phi_A = I \cdot \frac{\ell_1}{\sigma \cdot \frac{\pi}{4} (D^2)} = \frac{4I}{\pi \sigma} \cdot \frac{\ell_1}{D^2} \dots\dots (1)$$

$$\ell_1 = \frac{\pi \sigma (\phi_T - \phi_A)}{4I} \cdot D^2 \dots\dots (2)$$

In these equations:

- 25 ϕ_T is the corrosion-preventive potential (V•SCE) of titanium;
- ϕ_A is the potential (V•SCE) of the sacrificial anode;
- I is the corrosion-preventing electric current (A);
- σ is the conductivity of sea water (\mathcal{U}/cm); and
- D is the inner diameter (cm) of the circulating water pipe.

30 On the basis of the above equations, the value of the distance ℓ_1 in the case where aluminum is used for the sacrificial anode is calculated. The values of I and σ have heretofore not been made clear, but as a result of our experiments and analyses, it was confirmed that they lie within the following ranges.

$$1.0 \leq I \leq 3.0 \quad (\text{A})$$

$$0.03 \leq \sigma \leq 0.05 \quad (\mathcal{U}/\text{cm})$$

35 Accordingly, the minimum value of the mounting position of the sacrificial anode 9 can be calculated as follows. When $\phi_T \geq -0.6$ (V•SCE), and $\phi_A = -1.0$ (V•SCE),

$$\ell_1 \geq \frac{\pi \times 0.03 \times (-0.6 + 1.0)}{4 \times 3.0} \times D^2 = 0.003 \cdot D^2 \quad (\text{cm}).$$

40 Therefore, if the mounting position of the sacrificial anodes 9 is set at $\ell_1 \leq 0.003 \cdot D^2$ (cm), hydrogen embrittlement of the titanium used in the tube sheet 4 and the heat transmission tubes 3 can be prevented.

45 The above description relates to the case where aluminum is used for the sacrificial anodes 9. It was found, however, that, even when zinc is used, since the potential ϕ_A of a sacrificial anode made of zinc is substantially of the same value as that of aluminum, a similar effect of preventing hydrogen embrittlement of the titanium is obtained.

Next, the scope ℓ_2 of installation of a lining of high insulative property on the inner wall surface of the circulating water pipe 1 in the proximity of the heat exchanger is determined in the following manner.

50 In this case, it is necessary that, at the position of ℓ_2 from the bottom surface of the heat exchanger, the potential thereof be made equal to -770 mV•SCE, the corrosion preventive potential of carbon steel. Therefore, if Ohm's law is similarly applied, the following equation will be valid.

$$55 \quad \phi_R - \phi_A = I \cdot \frac{\ell_1 - \ell_2}{\sigma \cdot (\frac{\pi}{4} D^2)} = \frac{4I}{\pi \cdot \sigma} \cdot \frac{\ell_1 - \ell_2}{D^2} \dots\dots (3)$$

From the foregoing Equations (1) and (3), the following equations are derived:

5
$$\frac{\phi_T - \phi_R}{\phi_T - \phi_A} = \frac{\ell_2}{\ell_1} \dots\dots\dots (4)$$

10
$$\ell_2 = \left(\frac{\phi_T - \phi_R}{\phi_T - \phi_A} \right) \cdot \ell_1 \dots\dots\dots (5)$$

In these equations:

15 ϕ_R is the corrosion preventive potential of the carbon steel piping at the end part on the sacrificial anode side of the lining of high insulative property; and
 ϕ_T and ϕ_A are the same as in Equation (1).

Here, Equation (4) indicates that, when the values of ϕ_T , ϕ_A , and ϕ_R are determined, the ratio between the scope ℓ_2 of installation of the lining of the circulating water pipe 1 and the mounting position ℓ_1 of the sacrificial anodes 9 is determined irrespective of the values of the inner diameter D of the circulating water pipe, the corrosion prevention electric current I, the conductivity σ of the sea water, and other variables.

When, similarly as before, the relationships

- 20 $\phi_T \geq -0.6$ (V•SCE)
 $\phi_A = -1.0$ (V•SCE)
 $\phi_R \leq -0.77$ (V•SCE)

25 are substituted in Equation (5), the following relationship is obtained.

30
$$\ell_2 = \frac{(-0.6 + 0.77)}{(-0.6 + 1.0)} \times \ell_1 = 0.4 \cdot \ell_1 \text{ (cm)}.$$

Thus, by setting the scope of installation of the lining of high insulative property on the inner wall surface of the circulating water pipe 1 at $\ell_2 \geq 0.4 \cdot \ell_1$ (cm), prevention of corrosion of the carbon steel piping is made possible.

35 This invention will now be described with respect to preferred embodiments thereof.

In one example illustrated in FIG. 1, the circulating water pipe 1 for conducting sea water 5 into the heat transmission tubes 3 is connected to a chamber 2 of the heat exchanger (only one end of which is shown). A large number of the heat transmission tubes 3 are supported at their ends on one side by a tube sheet 4 of the heat exchanger. The inner wall surface of the circulating water pipe 1 (piping inner diameter D cm) is lined with a general type of coating 6 such as a tar-epoxy coating. The inner wall surface of the chamber 2 is provided with a lining 8 made of a material of electrically insulative property of high reliability containing a synthetic rubber material known from the past, e.g., a rubber lining. Furthermore, in the region of the scope indicated by ℓ_2 , the inner wall surface of the circulating water pipe 1 of its part in the proximity of the heat exchanger is provided with a further lining 7 of an electrically insulative material of high insulative property containing a known synthetic rubber material.

45 At a position spaced ℓ_1 from the bottom face of the heat exchanger chamber 2, sacrificial anodes 9 are mounted in the interior of the circulating water pipe 1. Furthermore, the circulating water pipe 1 and the chamber 2 are made of carbon steel, a metal material which is electrically baser than titanium, while the tube sheet 4 and the heat transmission tubes 3 are made of titanium. The sacrificial anode 9 is made of a metal material which is electrically baser than the material of which the circulating water pipe 1 is made.

In a piping system of the above described organization, the length ℓ_1 defining the mounting position of the sacrificial anodes 9 is determined by the relationship $\ell_1 \geq 0.003 \cdot D^2$ (cm) obtained hereinbefore. As a result, hydrogen embrittlement of the titanium used in the heat exchanging parts such as the tube sheet 4 and the heat transmission tubes 3 of the heat exchanger can be prevented.

55 Furthermore, the length ℓ_2 defining the region in which the inner wall surface of the circulating water pipe 1 is lined with an electrically insulative material of high insulativeness is determined from $\ell_2 \geq 0.4 \cdot \ell_1$ (cm) as described hereinabove, whereby prevention of corrosion of the carbon steel piping due to sea water can be prevented.

In another embodiment of this invention as illustrated in FIG. 3, the essential construction and arrangement of the heat transmission tubes 3, the tube sheet 4, the chamber 2, the circulating water pipe 1 are for the most part the same as those of the preceding example shown in FIG. 1. A point of difference is that, in the region defined by the length l_2 from the bottom face of the chamber 2, an insulative piping 10 made of an electrically insulative material such as vinyl chloride, another plastic, synthetic rubber material, or fiber-reinforced plastic (FRP) is installed.

Similarly as in the preceding example shown in FIG. 1, the inner wall surface of the chamber 2 is covered with a lining 8 of high reliability, and the inner wall surface of the circulating water pipe 1 connected to the end of the insulative piping 10 is covered with a lining made of an electrically insulative material of high insulativeness. At a position defined by the length l_1 from the bottom face of the heat exchanger chamber 2, sacrificial anodes 9 are mounted on inner parts of the circulating water pipe 1. The structural parts of the circulating water pipe 1 and the chamber 2 are made of carbon steel, while the tube sheet 4 and the heat transmission tubes 3 are made of titanium. The sacrificial anodes 9 are made of a metal material which is electrically baser than the material of which the circulating water pipe 1 is made.

In the piping system of the above described organization, the distance l_1 defining the mounting position of the sacrificial anodes 9 is determined as before from the relationship $l_1 \geq 0.003 \cdot D^2$ (cm). As a result, hydrogen embrittlement of the titanium used in the heat exchanging parts of the heat exchanger such as the tube sheet 4 and the tubes 3 is prevented.

Furthermore, the length l_2 of the region within which the insulative piping 10 is installed from the bottom face of the chamber 2 is determined from the relationship $l_2 \geq 0.4 \cdot l_1$.

Since the material of the insulative piping 10 of this example is an electrically insulative material containing a conventional synthetic rubber material, its electrical insulativeness is high, whereby an insulative effect equivalent to that afforded by a lining of high insulativeness applied on the inner wall surface of a carbon steel piping is obtained.

In accordance with this invention, by determining, on the basis of the calculation equations set forth hereinbefore, the length l_1 defining the mounting position of the sacrificial anodes and the length l_2 defining the region in which a lining 6 of high insulativeness is applied or, instead of a lining, an insulative piping 10 is installed, tube sheet 4 and the heat transmission tubes 3 can be maintained at potentials above that for preventing hydrogen embrittlement of the titanium of which these parts are made. At the same time, the carbon steel piping can be maintained at a potential below the potential for corrosion prevention thereof, whereby positive prevention of corrosion due to sea water of the heat exchanger and its piping system becomes possible.

Therefore, hydrogen embrittlement of the titanium used in the heat exchanging parts of a heat exchanger using sea water is prevented, and, moreover, galvanic corrosion of carbon steel piping connected to the heat exchanger is prevented, whereby the establishment of a cathodic protection apparatus of excellent reliability of a circulating water system using sea water of a power generating plant becomes possible.

The graph in FIG. 5 indicates distributions of potential along the centerline of the outlet chamber and the outlet circulating water pipe as determined from experiments and analyses. In this graph, the ordinate represents the potential at the centerline, while the abscissa represents longitudinal positions along the outlet chamber 9 and the outlet circulating water pipe 10, which are shown in juxtaposed alignment above the graph. The potential distribution shown is that in the case where an external power supply electrode 36 installed within the outlet pipe 10 was positioned at three different positions (a), (b), and (c), and the voltage value was so controlled that the same potential (approximately $-1,000$ mV \cdot SCE) was maintained. The measured values of the potential within the outlet chamber 9 and the outlet pipe 10 thus obtained were joined to obtain three distribution curves (a), (b), and (c).

First, curve (a) represents the potential distribution in the case where the mounting position of the external power supply electrode 36 was ideal. In this case, at a position somewhat toward the outlet chamber 9 side from the electrode 36, the potential becomes approximately -770 mV \cdot SCE and, within the outlet chamber 9, becomes a potential which is nobler than -500 mV \cdot SCE. That is, with approximately -770 mV \cdot SCE as a boundary point, the outlet pipe 10 and the outlet chamber 9 contiguous thereto, which exhibit potentials nobler than this boundary point, are within a region wherein a steel surface is readily eroded by electrolytic corrosion when a suitable countermeasure cannot be taken. On the other hand, the region of the outlet pipe 10 exhibiting a potential baser than approximately -770 mV \cdot SCE is a region in which electrical corrosion prevention has an effect, and the danger of electrolytic corrosion of a steel surface is slight.

According to the results of the above mentioned experiments and analyses, the region exhibiting potentials on the nobler side of approximately -770 mV \cdot SCE involving the danger of a steel surface being eroded by electrolytic corrosion, particularly the region exhibiting potentials higher than approximately -770

mV•SCE within the outlet chamber 9 and within the outlet pipe 10, is covered by suitably using a material of excellent electrical insulativeness. On the other hand, with respect to regions exhibiting potentials baser than approximately -770 mV•SCE, materials having corrosion preventive property are principally used for covering with consideration of suppression of corrosion of steel surfaces. With regard to the expansion joint 5 19 inserted in the outlet circulating pipe 10, since it is made of an insulative material such as rubber from the beginning, it may be excluded from considerations of electrical corrosion prevention.

Next, the curve (b) represents the potential distribution in the case where the external power supply electrode 36 is nearer the outlet chamber 9 than in the case of (a). In comparison with (a), the position exhibiting a potential of approximately -770 mV•SCE is nearer the outlet chamber 9 side. That is, the region 10 wherein the electrical corrosion prevention is effective is nearer the outlet chamber 9 than in (a), and the region covered by the material having electrical insulativeness is reduced by that much. However, the potential within the chamber 9 is considerably on the baser side in comparison with (a) at -500 mV•SCE and approaches -600 mV•SCE the potential entailing hydrogen embrittlement of titanium material. In the event that, because of a cause such as contamination of the tube sheet 22 and the cooling tubes 3, the 15 potential varies greatly and swings to the baser side, it may reach -600 mV•SCE. Thus, compared with (a), there is less leeway in the case of (b), which is therefore accompanied by the risk of hydrogen embrittlement which is higher by that much and cannot be easily adopted.

Furthermore, the potential distribution in the case where the external power supply electrode 36 is mounted at a position on the side of (a) opposite from (b) and farther from the chamber 9 is represented by 20 curve (c). In comparison with (a), the potential in this case within the chamber 9 shifts further toward the nobler side, whereby the potential entails no problem whatsoever with regard to hydrogen embrittlement of titanium material. However, in comparison with (a), the position at which the potential within the water pipe 10 indicates a value of approximately -770 mV•SCE is even further away from the chamber 9. That is, as a consequence of the shifting of the region over which the electrical corrosion prevention is effective, the 25 region to be covered by a material of electrical insulativeness spreads, and, on the contrary, the region to be covered with a corrosion preventive material becomes smaller. The expansion of the region covered by an electrically insulative material in this manner, in other words, the widening of the region over which the electrical corrosion prevention has no effect, must be considered with great caution in view of the possibility of damaging of the covering material. From the economical viewpoint, also, there is a limit to the application 30 of expensive insulative materials.

As a final conclusion, it can be said that the external power supply electrode 36 cannot be mounted at the position producing the potential distribution of curve (c) but is so positioned as to shorten the covered region. However, if the potential distribution assumes the form of curve (b) as described hereinbefore, the possibility of hydrogen embrittlement of the titanium material increases this time. Therefore, (a) is a 35 potential distribution in which the region wherein the electrical corrosion prevention has an effect is small and can be said to be a potential distribution which is not conducive to occurrence of hydrogen embrittlement of the titanium material.

On the other hand, in a separate experiment and analysis, the potential in the proximity of the external power supply electrode 36 was raised from approximately -1,000 mV•SCE of the preceding experiment to 40 approximately -1,500 mV•SCE, and the potential distribution was measured. The result is represented by the broken-line distribution curve (d) in FIG. 5. Compared with curve (a), it is apparent this distribution (d) affords an expansion of the region wherein the electrical corrosion prevention has an effect, but merely setting the potential at a high value causes the drawbacks to conspicuously outweigh the advantages. That is, the potential within the outlet chamber 9 approaches closely to -600 mV•SCE, and the risk of occurrence 45 of hydrogen embrittlement rises more and more. At the same time, since the potential is set on the baser side of -1,000 mV•SCE, peeling off of the insulative material readily occurs.

Therefore, it is desirable that the potential of the external power supply electrode 36 be limited to approximately -1,000 mV•SCE as a maximum.

Furthermore, the lower limit of the corrosion prevention potential is set at approximately -650 mV•SCE, 50 the natural potential of iron in sea water being -450 to -650 mV•SCE.

The present invention will now be described with respect to preferred embodiments thereof with reference to drawings.

Referring first to FIG. 4, the inner wall surface of the outlet chamber 9 of the condenser 2 is covered with a layer of a lining material having electrical insulativeness such as a layer of rubber 42 of strong 55 construction and grounded 25 by way of a structure. Below this chamber 9 is mounted a reference electrode 39a, which is coupled by way of a potential control device to an electrical corrosion prevention device 38 for generating a corrosion prevention electric current 37 and set at a potential on the nobler side of -600 mV•SCE and operates to transmit detection potential signals to the electrical corrosion prevention

device 38 so as to prevent hydrogen embrittlement of titanium material. The region ℓ_2 of the outlet circulating water pipe 10 contiguous to the chamber 9 is similarly lined with a rubber layer 42. Ordinarily, the expansion joint 19 installed in the outlet pipe 10 is made of rubber, where there are no exposed parts of steel surfaces in the region ℓ_2 .

5 The region of the outlet pipe 10 and other than that of ℓ_2 is lined with a covering layer material of tar-epoxy resin 43 having corrosion preventive property. A reference electrode 39b is installed at the boundary between the rubber lining 42 and the tar-epoxy resin lining 43. This reference electrode 39b is coupled by way of a potential control device 40b to the electrical corrosion prevention device 38 and set at a potential on the baser side of $-770 \text{ mV} \cdot \text{SCE}$ and operates to transmit detection potential signals to the electrical
10 corrosion prevention device 38 so as to prevent erosion of steel surfaces by electrolytic corrosion.

An external power supply electrode 36 controlled by the corrosion prevention device 38 is mounted on the inner surface of the outlet pipe 10 at a distance ℓ_1 from the lower or exit end of the chamber 9. Therefore, the region of electrical corrosion prevention is that of ℓ_3 , which is ℓ_1 minus ℓ_2 .

15 The results of measurement of the potential and electric current values at the lower part within the chamber 9 and the potential distribution within the outlet circulating water pipe 10 in the case where ℓ_1 is approximately 4.8 m, the inner diameter D of the outlet pipe 10 is 2.4 m, and the potential of the external power source electrode 36 is approximately $-1,000 \text{ mV} \cdot \text{SCE}$ will now be described.

First, the variation of the potential at the lower part within the chamber 9 will be considered.

20 In the graph shown in FIG. 6, the ordinate represents the potential at the centerline of the outlet pipe 10, while the abscissa represents the distance from the external power supply electrode 36 toward the condenser 2.

In the case where ℓ_1 is approximately 4.8 m and is approximately twice the inner diameter D, the potential distribution from the electrode 36 to the point approximately 4.8 m therefrom is represented by the curve (g), from which it can be seen that the potential at the lower part of the chamber 9 is on the nobler
25 side of $-600 \text{ mV} \cdot \text{SCE}$. In this case, the potentials in the region from approximately 4.8 m to approximately 3.3 m are on the nobler side of $-600 \text{ mV} \cdot \text{SCE}$, and within this region, hydrogen embrittlement of titanium material will not occur.

In FIG. 6 the potential distributions when ℓ_1 is approximately 2.4 m and when it is approximately 1.2 m are represented by curves (h) and (i), respectively. These values of ℓ_1 are respectively 1.0 times and 0.5
30 times the above stated inner diameter of 2.4 m of the outlet pipe 10. The potentials of these curves (h) and (i) are always on the baser side of $-600 \text{ mV} \cdot \text{SCE}$, whereby hydrogen embrittlement of titanium material will occur. Accordingly, it is necessary to space the electrode 36 at a distance ℓ_1 which is at least twice the inner diameter D as in the case of (g).

Next, the variation of the electric current will be considered.

35 In FIG. 7 the ordinate of the graph shown therein represents the current from the external power supply electrode 36, while the abscissa represents the distance from the condenser to the electrode 36. From this graph, it can be seen that, for distances greater than 4.8 m, the current becomes substantially constant at 2 amperes. As the distance decreases from 4.8 m, the current rises rapidly.

40 Next, the potential distribution within the circulating water pipe 10 will be considered. In this case, the conditions are the same as those of FIGS. 6 and 7, but the case where the potential of the external power supply electrode 36 is constant at approximately $-1,500 \text{ mV} \cdot \text{SCE}$ will be described.

In FIG. 8, the ordinate of the graph shown therein represents the potential at the centerline of the outlet pipe 10 on the condenser side of the electrode 36, while the abscissa represents the distance from the electrode toward the condenser.

45 In this graph, curve (j) indicates the potential distribution within the outlet pipe 10 in the case where the potential of the electrode 36 is approximately $-1,000 \text{ mV} \cdot \text{SCE}$. Although some differences occur depending on the current value, the potential distribution is in a region which is baser than $-770 \text{ mV} \cdot \text{SCE}$ at a distance from the electrode 36 of approximately 2.4 m or less, and the desired prevention of corrosion of steel surfaces is attained. On the other hand, in the region where the distance exceeds 2.4 m (indicated by
50 inclined hatch lines), the potential becomes nobler than $-770 \text{ mV} \cdot \text{SCE}$, and the corrosion prevention effect cannot be obtained.

For comparison with curve (j), the potential distribution at the centerline of the chamber 9 and the outlet pipe 10 in the case where the potential of the external power supply electrode 36 is approximately $-1,500 \text{ mV} \cdot \text{SCE}$ is indicated by curve (k) in FIG. 8. While some differences occur depending on the current value,
55 the potential distribution in the region at distances at approximately 4.1 m or less from the electrode 36 is on the baser side of $-770 \text{ mV} \cdot \text{SCE}$, and the corrosion prevention is effective over a wider region than in the case of curve (j). However, this potential is not a potential (approximately $-1,000 \text{ mV} \cdot \text{SCE}$) to maintain the potential of the lower part within the chamber 9 at a reasonable value as indicated by curve (g) in FIG. 3

and cannot be relied upon.

On the basis of the above referred to FIGS. 6, 7, and 8, since the region in which the corrosion prevention effect can be obtained is approximately 2.4 m when the mounting position of the external power electrode 36 is approximately 4.8 m, the length l_2 becomes $l_1 - l_3 = 4.8 - 2.4 = 2.4$, whereby the region
5 lined with a material having insulative property in this case becomes approximately 2.4 m and more in axial length.

In another embodiment of this invention, as will now be described hereunder, the potential of the external power supply electrode 36 is maintained at approximately $-700 \text{ mV} \cdot \text{SCE}$ which is a potential that is nobler than $-770 \text{ mV} \cdot \text{SCE}$. This mode of practice may be considered particularly for the case where it is
10 desired to increase the economization effect by a measure such as setting the potential on the nobler side relative to that of the preceding example thereby to reduce the electric current value or reducing the area of the covering lining made of high-priced rubber.

In the instant example shown in FIG. 9, the interior wall surfaces of the outlet chamber 9 and the adjacent region of the length l_2 are covered by a rubber layer 42 of a strong construction, similarly as in
15 the preceding example. In these places, there are no steel surfaces exposed to the sea water. It is to be noted that an expansion joint 19 is included in this region of the length l_2 . The inner wall surface of the outlet circulating water pipe 10 other than that included in the length l_2 is covered by a tar-epoxy resin 43. The external power supply electrode 36 is installed at a position at the distance l_1 within this covered region. The difference l_3 obtained by subtracting l_2 from l_1 is the length of the region of electrical
20 corrosion prevention in this case.

The results of measurement of the potential at the lower part of the chamber 9, the electric current value, and the potential distribution in the outlet pipe 10 in the case where l_1 was approximately 3.6 m; the inner diameter of the outlet pipe 10 was 2.4 m; and the potential of the electrode 36 was approximately
-700 $\text{mV} \cdot \text{SCE}$ will now be described.

First, the variation of the potential at the lower part within the chamber 9 will be described with reference to FIG. 10. In the graph shown in FIG. 10, the ordinate represents the potential at the centerline of the outlet pipe 10, while the abscissa represents the distance from the external power supply electrode 36
25 toward the condenser 2.

The potential distribution in the case where l_1 is approximately 3.6 m ($l_1/D \doteq 1.5$), that is, from the electrode 36 to a point apart therefrom by approximately 3.6 m is represented by curve (l). In this case, the potential at the lower part within the chamber 9 is on the nobler side of $-600 \text{ mV} \cdot \text{SCE}$, hydrogen embrittlement of titanium material does not occur.

In the same graph, curves (m) and (n) represent potentials respectively for l_1 of 0.5 m ($l_1/D \doteq 0.2$) and l_3 of 0.24 m ($l_3/D \doteq 0.1$). In either case, the potentials are on the baser side of $-600 \text{ mV} \cdot \text{SCE}$, and therefore hydrogen embrittlement of titanium material occurs. Accordingly, it is necessary that l_1 be 1.5
35 times D.

The variation of the current value is indicated by the graph shown in FIG. 11, in which the ordinate represents the current value from the electrode 36, while the abscissa represents the distance from the condenser 2 toward the electrode 36. It can be seen from this graph that the current is substantially
40 constant at slightly below 0.2 ampere at distances greater than 3.6 m. On the other hand, at shorter distances, the current rapidly rises.

Next, the potential distribution within the outlet pipe 10 will be described with reference to FIG. 12, which is a graph in which the ordinate represents the potential at the centerline of the outlet pipe 10 in its region from the electrode 36 toward the condenser, while the abscissa represents the distance from the
45 electrode 36 toward the condenser.

In this graph, the curve (o) represents the potential distribution in the outlet pipe 10 in the case where the potential of the electrode 36 is approximately $-700 \text{ mV} \cdot \text{SCE}$. While there are some differences depending on the current value, the region within a distance of 1.7 m from the electrode 36 is that of a potential distribution on the baser side of approximately $-650 \text{ mV} \cdot \text{SCE}$, in which region prevention of
50 corrosion of steel surfaces presents substantially no problem. On the other hand, the region at distances exceeding 1.7 m (curve (o) marked with inclined hatching) becomes than on the nobler side of approximately $-650 \text{ mV} \cdot \text{SCE}$, wherein a corrosion preventive effect cannot be obtained.

The set potential of the outlet pipe 10 of the instant example is at the limit of the natural potential of iron in sea water and is on the nobler side of the $-770 \text{ mV} \cdot \text{SCE}$ of the preceding example. For this reason, the reliability is somewhat impaired, but, if economy is to be regarded important, it becomes possible by the
55 instant example to obtain a satisfactory effect.

A method differing from those of the preceding examples will now be described with reference to FIG. 13. The organization of the example shown in FIG. 13 differs from that of the example illustrated in FIG. 9 in

that the reference electrodes 44a and 44b have been changed from a zinc material to a steel material, and their potential is set at the natural potential of iron in sea water. More specifically, in the case where reference electrodes of steel material are used, it is possible, when the potential in the vicinity of the reference electrodes 44a and 44b becomes nobler than the natural potential of iron in sea water, to immediately detect the potential of the reference electrodes themselves and pass a corrosion preventive current and when, on the other hand, the above mentioned potential becomes baser than the natural potential of iron in sea water, to immediately detect this and reduce the corrosion preventive current. Thus, it is advantageously possible to accurately and positively grasp the state of corrosion and corrosion prevention of the steel surface.

With the use of reference electrodes made of ordinary zinc material or the like, some deviations or irregularities occur in the measured potentials, and errors become a problem. In the case of a reference electrode of zinc of the above described example, the question of selecting the set potential is also difficult. For example, even in the case where the set potential is selected at $-550 \text{ mV} \cdot \text{SCE}$, problems such as time delay of the detected potential, deviation of the natural potential of the zinc material, deviations due to the environmental conditions, and deviation of the potential at the time of zinc polarization are encountered, and errors in the measured potentials must be considered. However, by the use of reference electrodes 44a and 44b of steel material, such errors no longer become a source of concern.

As described above, according to this invention, the inner wall surface of each chamber in entirety and the inner wall surface of the piping contiguous to that chamber over a specific region are covered with a lining of an amply strong electrically insulative material so as to preserve the insulated states of these parts, and the corrosion prevention potential within each chamber and the piping connected thereto is maintained by so controlling the voltage and current values therewithin as to maintain a potential capable of suppressing hydrogen embrittlement of the titanium material within each chamber in the vicinity of the lower part of the adjoining tube sheet and a potential on the baser side of the natural potential of iron, at least in sea water, within the piping in the vicinity of the boundary between each specific region and the contiguous part of the piping not thus provided with the lining.

Claims

1. A cathodic protection apparatus for preventing galvanic corrosion in a sea water circulation system of an all-titanium heat exchanger having a shell, a pair of titanium-material tube sheets closing opposite ends of said shell, a plurality of titanium-material heat transfer tubes supported by and extending through and between said tube sheets, and a pair of chambers connected to the ends of said shell, said chambers being connected to opposite piping of a sea water circulation system, said chambers and said piping made of a metal material which is electrically baser than said titanium material, the inner wall surface of each chamber in entirety being covered with a lining of a substantially strong electrically insulative material, characterized in that said apparatus comprises: an electrically insulative material provided as a lining (7) on the inner wall surface of said piping (1) in a specific region (ℓ_2) thereof contiguously from a bottom face of each chamber (2), and at least one cathodic protection means (9) installed within said piping (1) at a position spaced apart by a specific distance (ℓ_1) from the bottom face of each chamber (2), which said specific distance (ℓ_1) is longer than the length of said specific region (ℓ_2).

2. The cathodic protection apparatus as claimed in claim 1 in which said cathodic protection means comprises: sacrificial anodes (9) made of a metal material which is electrically baser than the material of said piping (1) and installed respectively in said piping (1) within respective regions such that each region is defined by the relationship $\ell_1 \geq 0.003 \cdot D^2$ (cm), wherein ℓ_1 is the distance from the bottom face of the corresponding chamber (2) to the sacrificial anode (9) and D is the inner diameter of the piping, the region in which said lining is provided in each piping or in which said piping itself is made of an electrically insulative material being defined by the relationship $\ell_2 \geq 0.4 \cdot \ell_1$ (cm), wherein ℓ_2 is the length of said region in the pipe axial direction.

3. The cathodic protection apparatus as claimed in claim 2 in which said sacrificial anode (9) is disposed within a device separated by approximately 4.8 m from the bottom face of each chamber (2).

4. The cathodic protection apparatus as claimed in claim 2 in which said specific region (ℓ_2) extends approximately 2.4 m in axial length from the bottom face of each chamber (2) and, in order to maintain corrosion prevention potentials within each chamber (2) and the adjoining piping (1), said sacrificial anode (9) is so installed within said piping (1) that the potential within each chamber in the vicinity of the lower part

of the adjoining tube sheet (4) will be maintained at approximately -600 mV•SCE, and that the potential at a point approximately 2.4 m from the bottom face of each chamber (2) will be maintained at approximately -770 mV•SCE.

5 5. The cathodic protection apparatus as claimed in claim 1 in which said cathodic protection means is a potential-maintaining electrode (36).

6. The cathodic protection apparatus as claimed in claim 5 in which said apparatus further comprises: detection electrodes (39a) installed respectively in each chamber (9) in the vicinity of the lower part of the tube sheets (22) and in the piping (10) in the vicinity of the boundary between each said specific region (ℓ_2) and the contiguous part of the piping not thus provided with said lining.

10 7. The cathodic protection apparatus as claimed in claim 5 in which said potential-maintaining electrode (36) is an external power supply electrode disposed within a device separated by approximately 4.8 m from the bottom face of each chamber (9).

8. The cathodic protection apparatus as claimed in claim 5 in which said specific region (ℓ_2) extends approximately 2.4 m in axial length from the bottom face of each chamber (9), and, in order to maintain corrosion prevention potentials within each chamber (9) and the adjoining piping (10), said electrode is so installed within said piping (10) that the potential within each chamber in the vicinity of the lower part of the adjoining tube sheet (22) will be maintained at approximately -600 mV•SCE, and that the potential at a point approximately 2.4 m from the bottom face of each chamber (9) will be maintained at approximately -770 mV•SCE.

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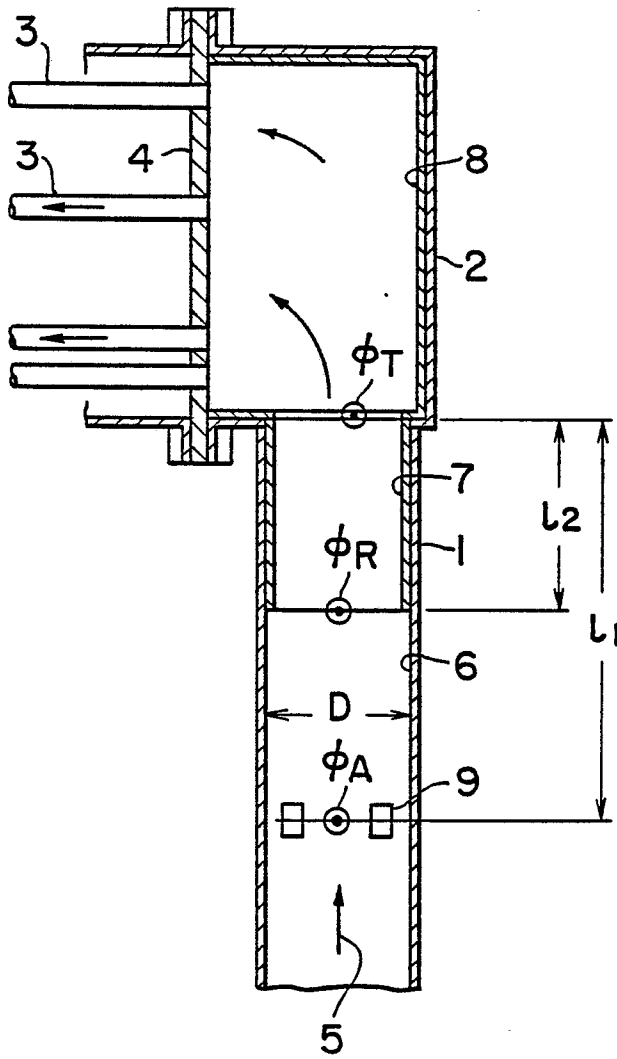


FIG. 1

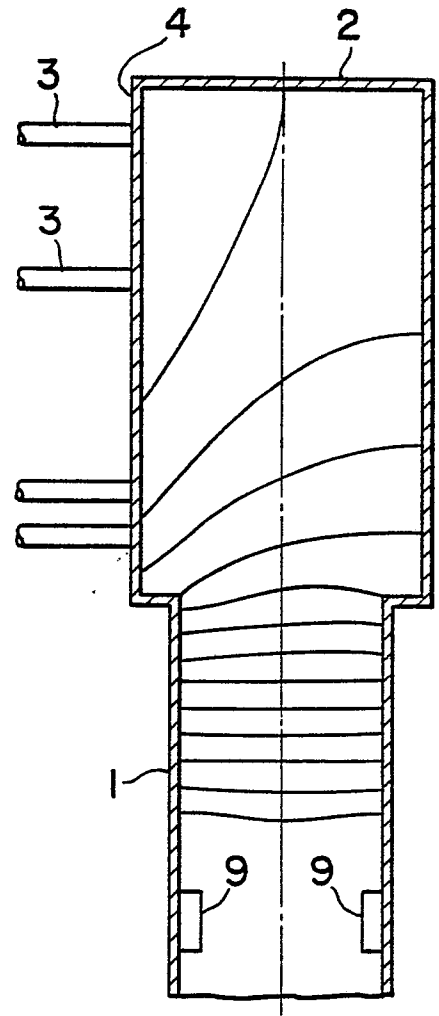


FIG. 2

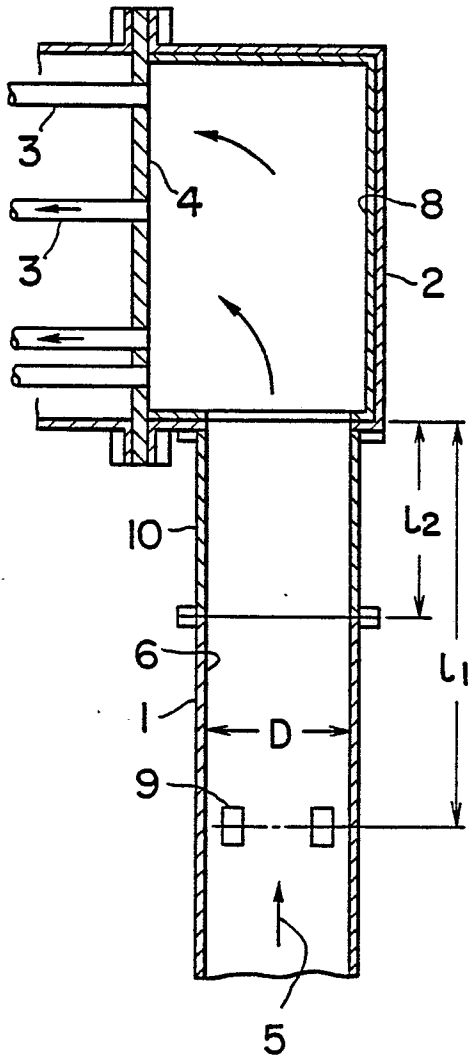


FIG. 3

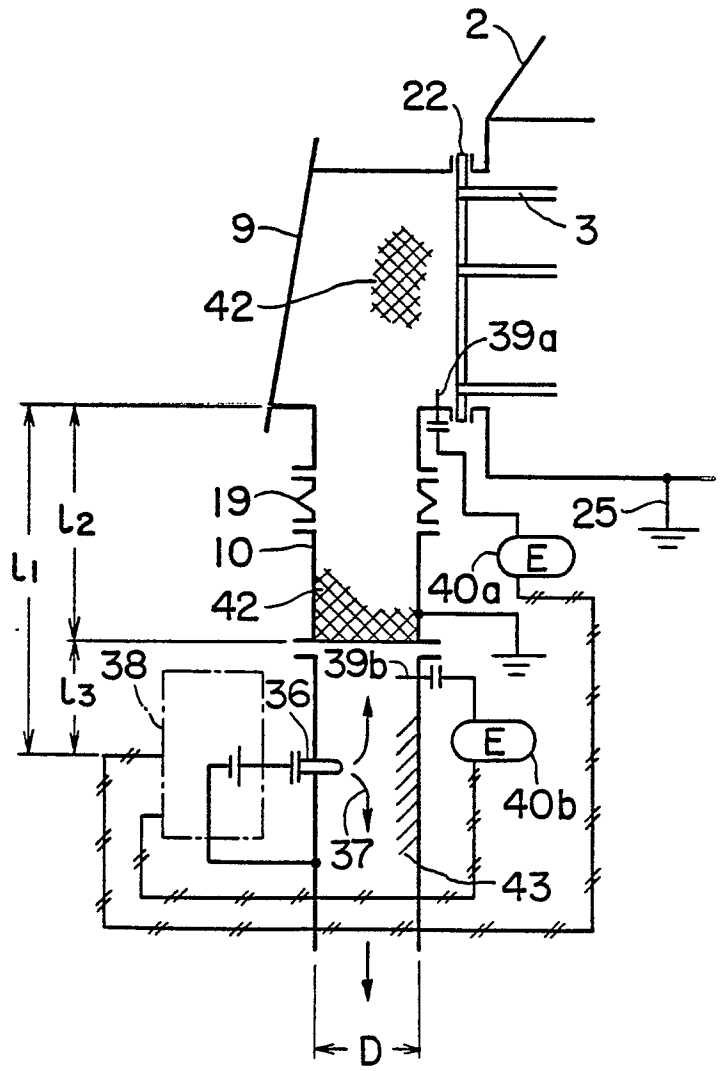


FIG. 4

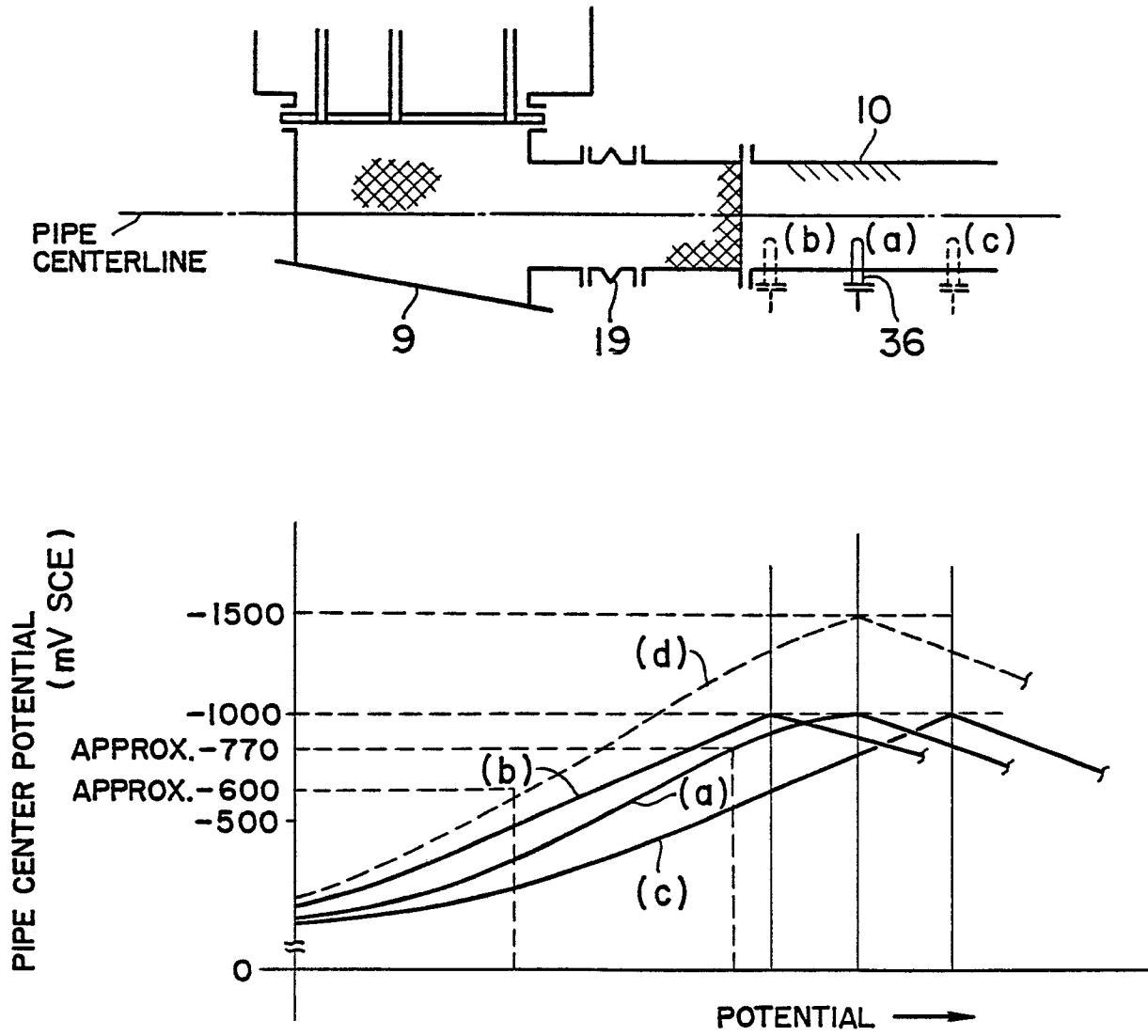


FIG. 5

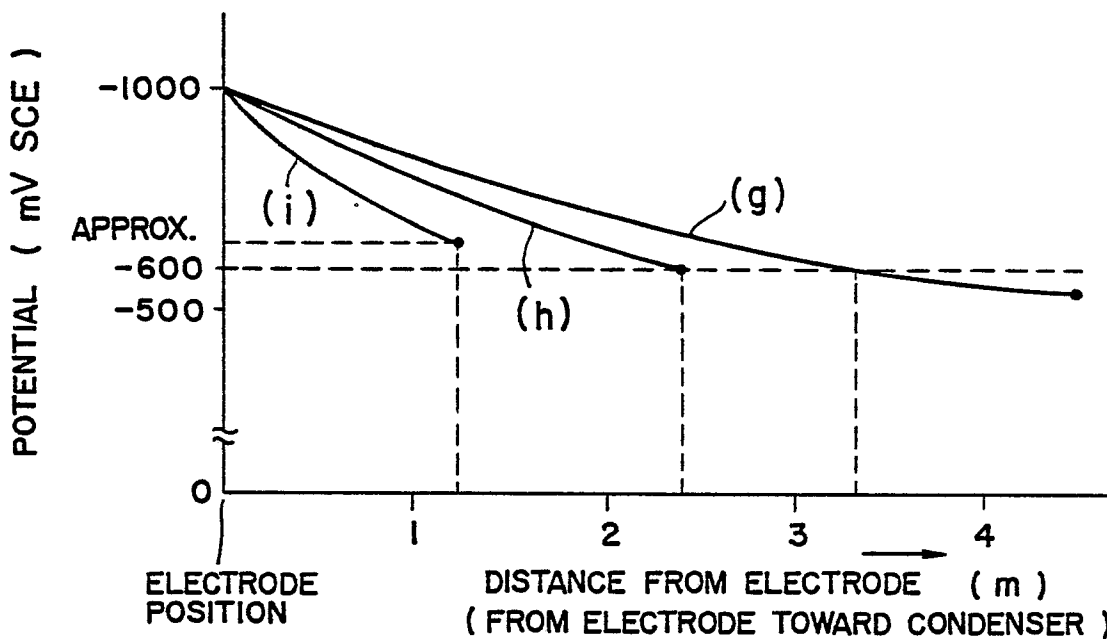


FIG. 6

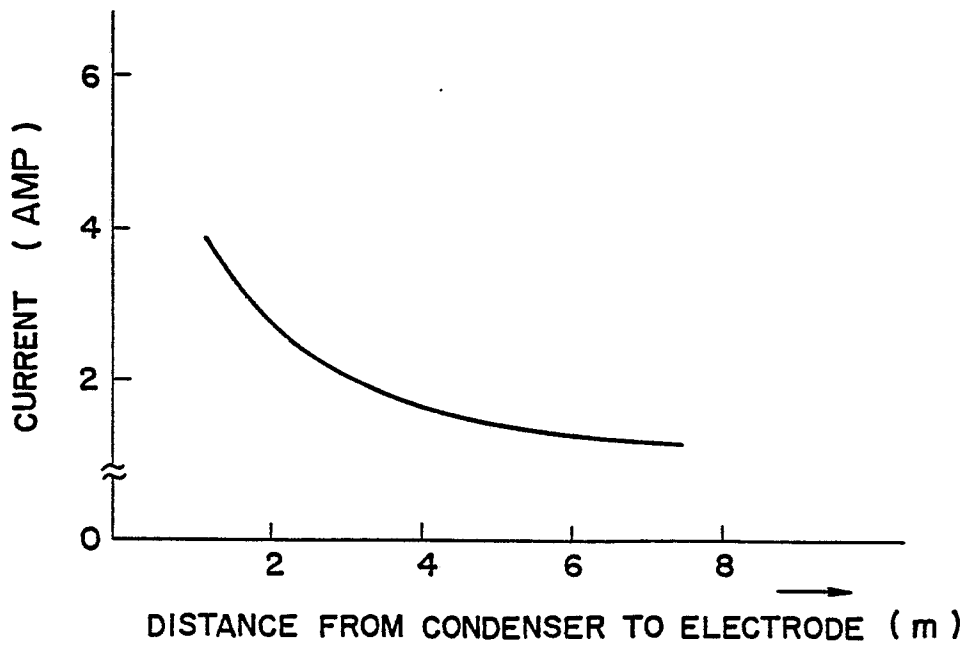


FIG. 7

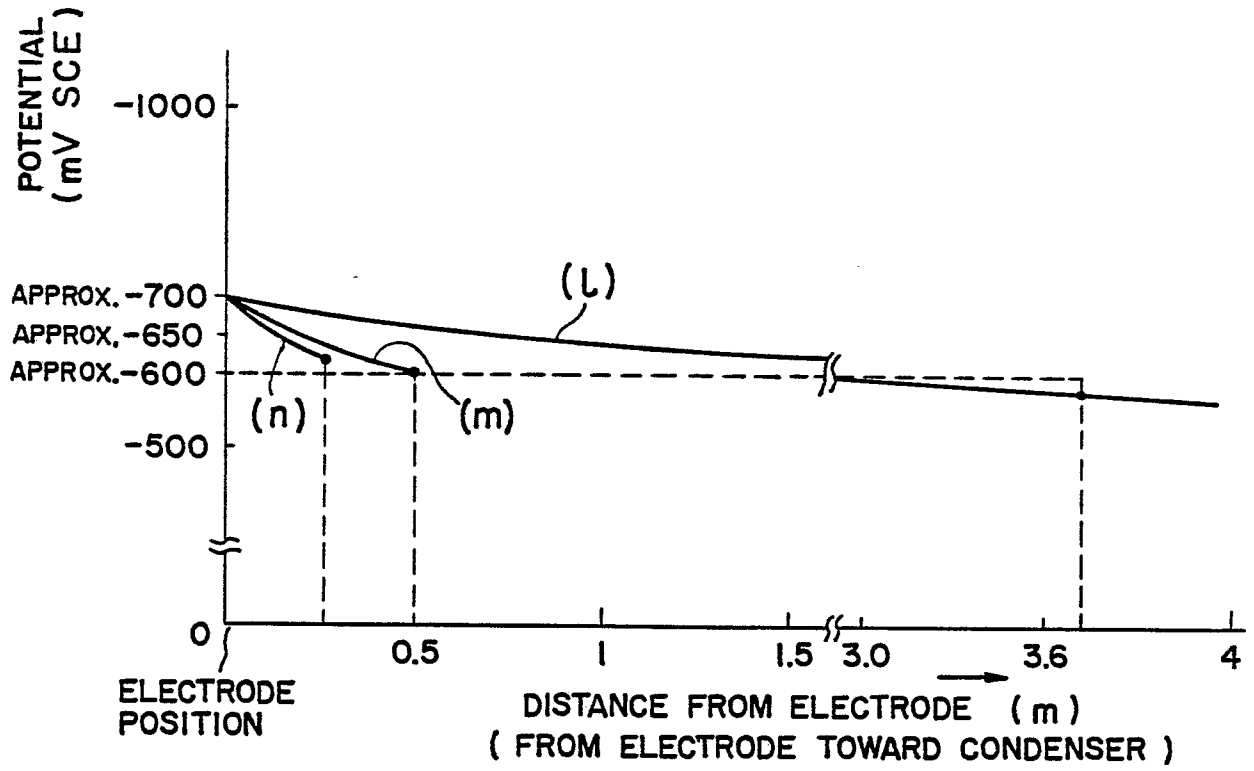


FIG. 10

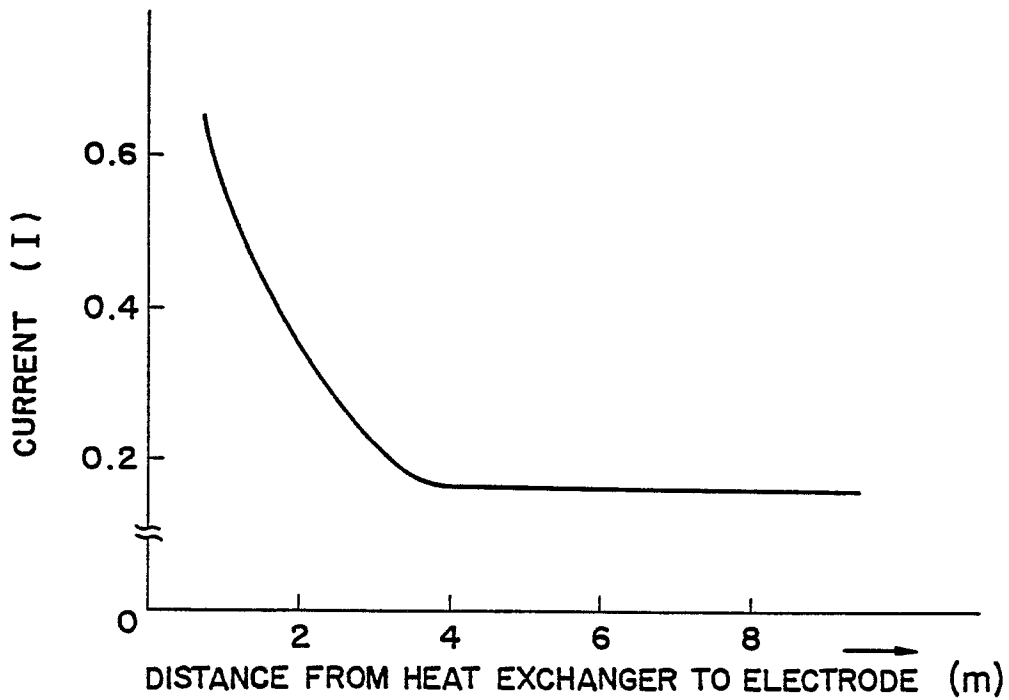


FIG. 11

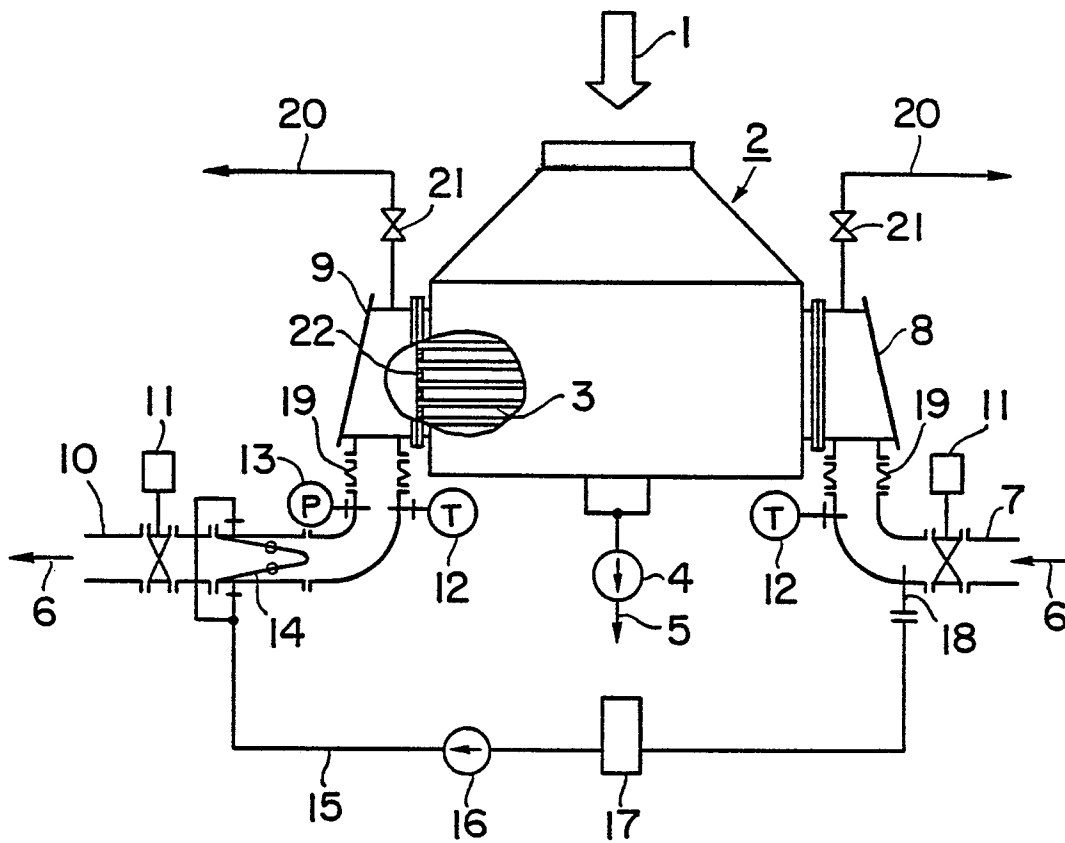


FIG. 14 PRIOR ART

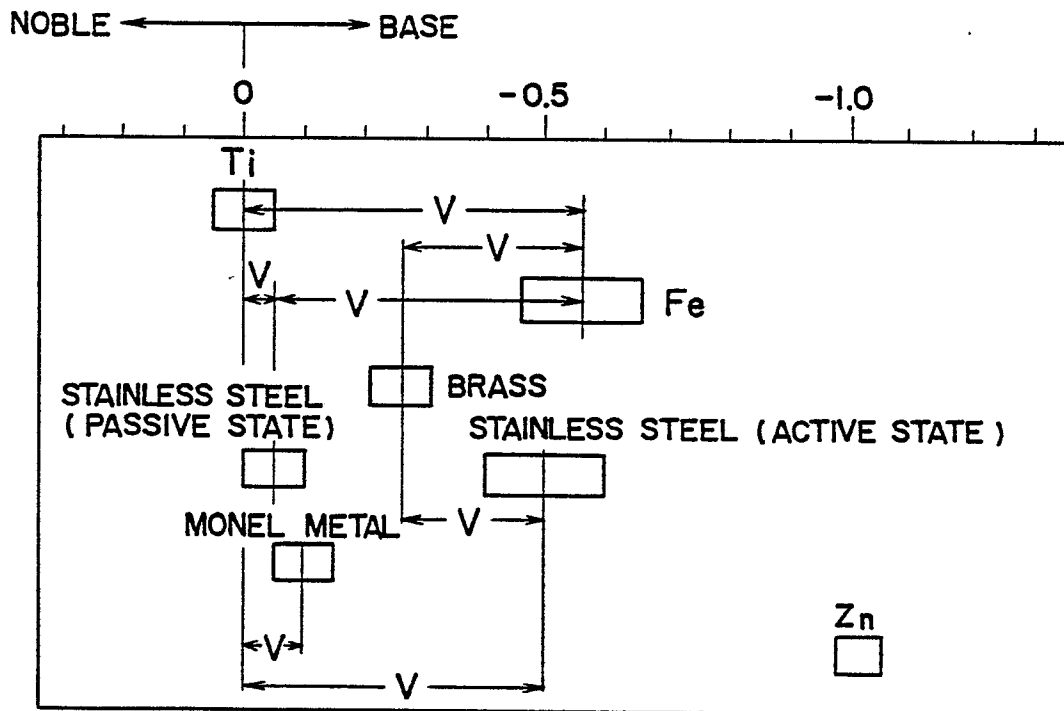


FIG. 15

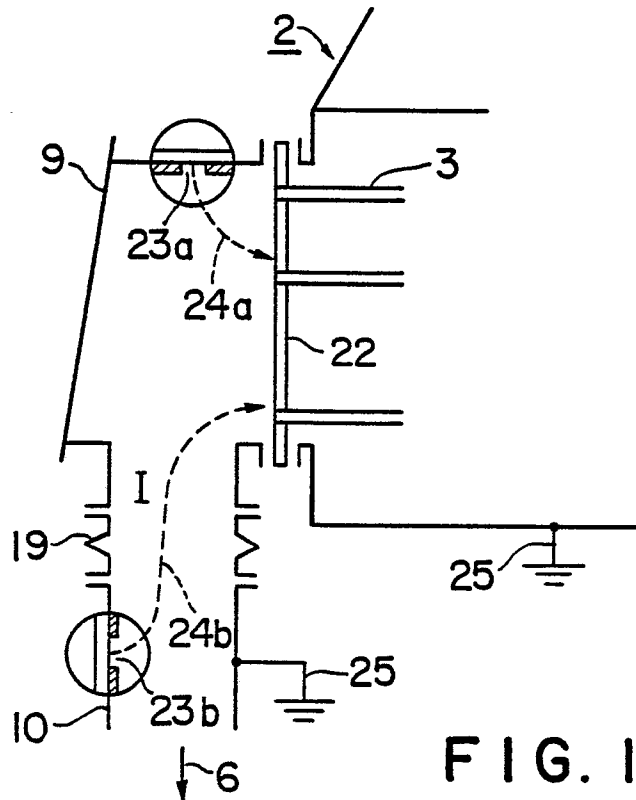


FIG. 16

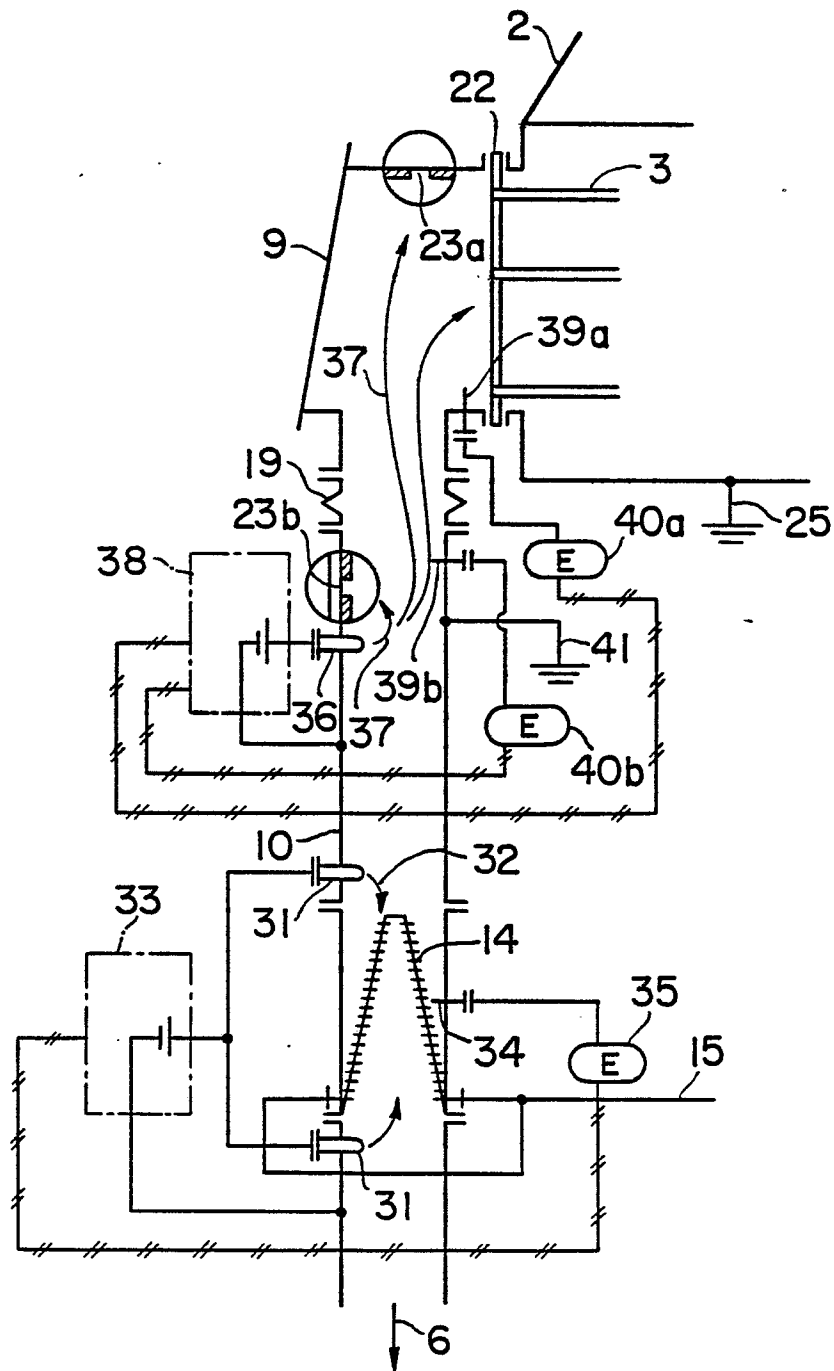


FIG. 19 PRIOR ART



DOCUMENTS CONSIDERED TO BE RELEVANT			EP 89100352.7
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)
A	<p><u>US - A - 4 457 821</u> (SUDRABIN et al.)</p> <p>* Column 3, line 63 - column 4, line 44; fig. 3-6 *</p> <p>--</p>	1	C 23 F 13/02
A	<p><u>GB - A - 1 232 334</u> (HERBERT ROSE)</p> <p>* Page 2, line 35 - page 3, line 9; fig. 1,2 *</p> <p>----</p>	1,2,4	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			C 23 F
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
VIENNA		16-04-1989	HAUSWIRTH
CATEGORY OF CITED DOCUMENTS			
<p>X : particularly relevant if taken alone</p> <p>Y : particularly relevant if combined with another document of the same category</p> <p>A : technological background</p> <p>O : non-written disclosure</p> <p>P : intermediate document</p>		<p>T : theory or principle underlying the invention</p> <p>E : earlier patent document, but published on, or after the filing date</p> <p>D : document cited in the application</p> <p>L : document cited for other reasons</p> <p>& : member of the same patent family, corresponding document</p>	