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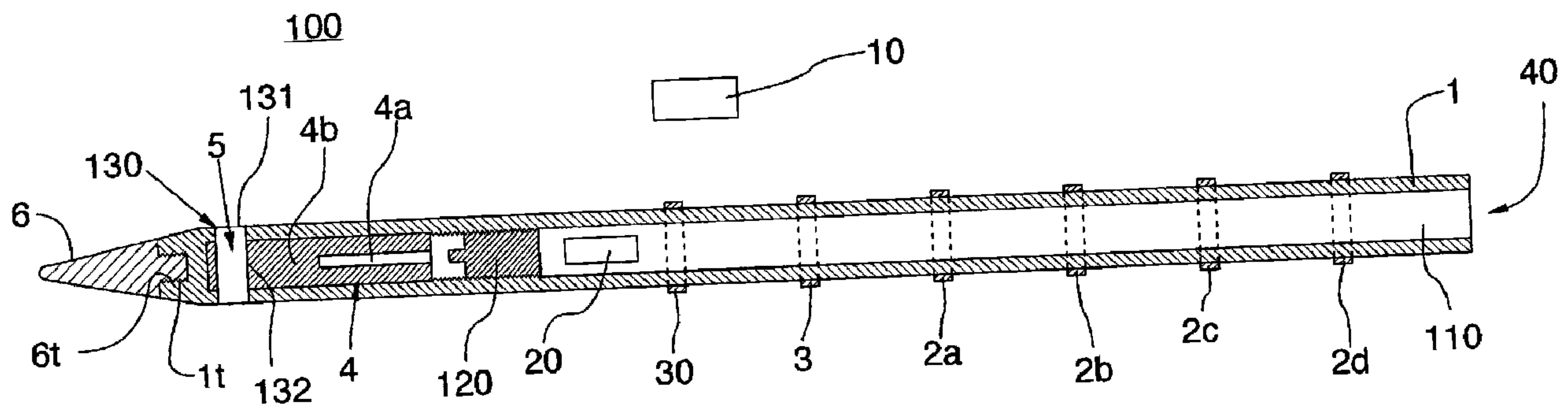
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(54) Title: SOIL PROBE



(57) Abrégé/Abstract:

A soil probe which enables the convenient testing of soil in field locations, particularly in the vicinity of oil and/or natural gas pipelines. The probe allows soil conditions which are associated with corrosive environments to be monitored. Most particularly, the probe facilitates the measurement of soil resistivity at different soil depths.

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Soil Probe**ABSTRACT**

30 A soil probe which enables the convenient testing of soil in field locations, particularly in the vicinity of oil and/or natural gas pipelines. The probe allows soil conditions which are associated with corrosive environments to be monitored. Most particularly, the probe facilitates the measurement of soil resistivity at different soil depths.

Soil ProbeFIELD OF THE INVENTION

This invention relates to a soil probe which enables the convenient testing of soil in field locations, particularly in locations in the vicinity of natural gas or oil pipelines.

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BACKGROUND OF THE INVENTION

External corrosion and environmental cracking problems are a significant threat to the integrity of gas transmission pipelines.

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Considerable effort is being spent to understand the mechanisms which cause corrosion and environmental cracking and identifying the conditions under which they occur. To date, correlations between conditions and materials at specific sites and the probability of integrity loss through a specific mechanism, have been determined as a result of extensive excavation programs. Targets for excavation are chosen by in line inspection (ILI) for parts of the system which are amenable to this technique. Where ILI is not practical, selection of potential sites remains largely a less scientific process.

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The corrosion of underground metallic structures is an electrochemical process, the rate of which is a function of the soil pH, resistivity, temperature and redox potential. The corrosion rate may also be influenced by the presence of bacteria (ref: R.L. Starkey and K.M. Wight, *Anaerobic Corrosion of Iron in Soil*, Am. Gas Assoc. Monograph,

1945). A number of probes have been developed for field measurement of some of the conditions that can contribute to the corrosion of metallic structures in soil. Deuber and Deuber, in association with the American Gas Association, developed a probe for field measurement of redox potentials (ref: C.G. Deuber and G.B. Deuber, *Development of the Redox Probe*, Final Report to the American Gas Association, Research Project PM-20, New York, 1956). Costanzo and McVey developed this probe further. Their probe consisted of two platinum electrodes coupled to a saturated calomel reference electrode (ref: F.E. Costanzo and R.E. McVey, 1958, *Development of the Redox Probe Field Technique*, Corrosion - NACE, **14**: 268T-272T). A similar probe for field determination of redox potentials was developed by Booth *et al*. By measuring soil redox potentials, soil resistivity and soil pH, Booth *et al* have developed soil aggressivity models for steel exposed to soil environments (ref: G.H. Booth, A.W. Cooper, P.M. Cooper and D.S. Wakerley, 1967, *Criteria of Soil Aggressiveness Towards Buried Metals, I. Experimental Methods*, Br. Corros. J., **2**: 104 - 108; G.H. Booth, A.W. Cooper and P.M. Cooper, 1967, *Criteria of Soil Aggressiveness Towards Buried Metals, II. Assessment of Various Soils*, Br. Corros. J., **2**: 109 - 113; and G.H. Booth, A.W. Cooper and A.K. Tiller, 1967, *Criteria of Soil Aggressiveness Towards Buried Metals, III. Verification of Predicted Behaviour of Selected Soils*, Br. Corros. J., **2**: 114 - 118).

Other parameters which influence the corrosivity of soil include soil resistivity and pH.

Local soil resistivity is typically measured by a test known as the Wenner four point method, in which:

- a) four pins are inserted into the soil being tested;
- 10 b) an alternating current (a/c) is applied to the two outer pins
 (i.e. the pins farthest from each other); and
- c) the drop in a/c potential between the two inner pins is
 measured,

(ref: F. Wenner, Bur. Stand. Sci. Pap. No 12, 469, 1916). This test is inconvenient, and provides a result, which is indicative of an average soil resistivity.

20 Thus a need exists for a soil probe which allows soil resistivity to be conveniently measured at different soil depths.

A further need is for a probe that can measure resistivity; redox; pH; and temperature, all in one probe unit.

SUMMARY OF THE INVENTION

30 In one embodiment of the invention there is provided a soil probe comprising:

- a) an elongated casing having a longitudinal length; and

b) at least four metallic rings (or bands) in contact with said casing such that said metallic rings are displaced from one another along said longitudinal length.

5 In another aspect of the invention, there is provided a soil probe comprising: an elongate housing having a longitudinal length; first, second, third, and fourth metallic rings mounted over the housing, the metallic rings being spaced along the length, respectively; wherein the first and fourth metallic rings receive an input voltage applied therebetween; and, wherein the second and third metallic rings access an
10 output voltage therebetween for comparing to the input voltage to determine a resistivity of a soil probe into which the probe is inserted.

 In another aspect of the invention, there is provided a soil probe comprising: an elongate housing having a longitudinal length for inserting into a soil; a reference cell
15 formed in the housing for providing a reference voltage, the reference cell having an electrode in contact with an electrolyte, the electrolyte being in contact with a porous sample port, the porous sample port being in contact with the soil through at least one hole in the housing; and, a metallic ring mounted over the housing; wherein the metallic ring and the electrode access an output voltage therebetween for determining,
20 with the reference voltage, an oxidation/reduction potential of the soil.

 In another aspect of the invention, there is provided a soil probe comprising: an elongate housing having a longitudinal length for inserting into a soil; a reference cell formed in the housing for providing a reference voltage, the reference cell having an
25 electrode in contact with an electrolyte, the electrolyte being in contact with a porous sample port, the porous sample port being in contact with the soil through at least one hole in the housing; and, a metal/metal oxide ring mounted over the housing; wherein the metal/metal oxide ring and the electrode access an output voltage therebetween for determining, with the reference voltage, a pH level of the soil.

This soil probe enables soil resistivity to be conveniently measured at different depths, in field locations.

5 In preferred embodiments of this invention, the present soil probe is also suitable for the measurement of redox potential; temperature; pH and pipe soil potential.

DETAILED DESCRIPTION

10 **BRIEF DESCRIPTION OF THE DRAWING**

Further details regarding the invention are provided with reference to Figure 1 which is a cross-sectional, side view of a soil probe 100 according to a preferred embodiment of the invention.

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Referring now to Figure 1, the preferred soil probe 100 includes a hollow cylindrical housing (or casing) 1 which may be constituted of any material which can withstand field use. Inexpensive materials such as polyethylene are preferred for reasons including ease of fabrication and low cost. The housing 1 is preferably non-
20 conducting.

Four metallic rings (or bands) 2a, 2b, 2c, 2d are mounted over the housing 1 at distances which are longitudinally spaced along the housing 1. These rings 2a, 2b, 2c, 2d are required for the soil resistivity test (analogous to the Wenner four point test) as
25 will be described later. The rings 2a, 2b, 2c, 2d may be manufactured from an inexpensive material such as stainless steel, though platinum (Pt) is preferred.

The probe 100 also preferably contains a reference cell 4 consisting of reference electrode 4a and reference electrolyte 4b. In the preferred reference cell 4, for reasons of cost and performance, the reference electrode 4a is a copper reference anode and the reference electrolyte 4b is a copper sulphate reference electrolyte. Such reference cells are widely available items of commerce. According to one embodiment, an element 120 within the housing 1 may separate the interior 110 of the housing 1 from the electrode 4a.

10 The soil probe 100 shown in the figure also includes a metallic ring (or band) 3 which, in combination with the reference cell 4, may be used to determine the soil redox potential as will be discussed later. The metallic ring 3 is preferably constructed from Pt and is mounted over the housing 1.

A porous sample port 5 is located near the tip 6 of the probe 100. The tip 6 is preferably fabricated from hardened steel to facilitate insertion of the probe 100 into the soil being tested. As shown in the figure, the tip 6 may be threaded at 6t so as to cooperate with threaded fitting 1t of the housing 1.

The porous sample port 5 shown in the figure is preferably a cylindrical plug which is inserted into a corresponding hole 130 in the housing 1. The porous sample port 5 is thus in contact with the environment (such as the soil, when the probe is in use) at a first end 131. The porous sample port 5 is also in contact with the reference electrolyte 4b at a second end (or side) 132. The porous sample port 5 should be constructed of materials which can withstand the rigor
20 of field use, such as a porous ceramic, though it is possible to employ many of the porous sample-contacting materials which are typically used in combination with commercially available reference cells.

In a highly preferred embodiment, a metal/metal oxide ring (or band) 30 is also included in the soil probe 100, mounted over the housing 1. This metal/metal oxide ring 30 is preferably a ruthenium ring which is sputtered with ruthenium oxide, and is used in combination with the reference cell 4 to measure a potential which is representative of pH.

A thermistor (schematically illustrated by reference numeral 20) may be included for the purpose of measuring soil temperature. As explained below, the thermistor 20 is located within the interior 110 of the housing 1.

The function of these parts in the measurement of soil resistivity, temperature, pH and potential is now described below.

10 **TEST PROCEDURES**

Soil Resistivity

The prior art procedure for measuring soil resistivity is commonly known as the Wenner four point method which, as previously mentioned, is undertaken by:

- a) inserting four metallic pins into the soil being tested (in a manner such that the pins form an essentially straight line);
- b) applying a/c to the two pins which are farthest apart from one another; and

c) measuring the a/c potential drop between the inner two pins.

This prior art procedure suffers from the disadvantage of being inconvenient and also poses a technical disadvantage in that it is generally considered to provide an "average" result for a cumulative depth.

10 The soil probe of this invention mitigates these disadvantages.

In particular, the four metallic rings 2a-d are analogous to the four points of the Wenner method. Thus, when the soil probe is inserted into the soil being tested, it may be positioned such that the four metallic rings 2a-d are in contact with the soil. By applying an a/c signal to the two rings which are furthest displaced from one another along the length of the probe casing (i.e. the outer rings, namely rings 2a and 2d in the figure) and measuring the a/c potential drop across the other two rings (i.e. between rings 2b and 2c), a result which is indicative of local soil resistivity is obtained. [It will be apparent to those skilled in the art that a suitable a/c source, a meter to measure potential drop and suitable connections to the probe, source and meter are required. These are not shown in detail in the figure for reasons of clarity, although the required meter is schematically represented by numeral 10. The construction and use of these connections and meters is trivial to a skilled person.] An a/c source which provides a signal of 1 kHz is preferred.

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As will be apparent from this description, soil resistivity may be conveniently measured at different depths by changing the depth that the probe is inserted into the soil.

Soil Temperature

10 The preferred casing 1 of the soil probe shown in the figure is hollow. Accordingly, a thermistor for measuring soil temperature may be readily enclosed with the soil probe. However, if the casing 1 is largely constructed from a poorly thermal conducting material such as polyethylene, some care should be taken to position the thermistor in a location where thermal conduction occurs (for example, close to the metal tip 6 or one of the metal rings 2, 3, 30).

pH

20 The soil probe shown in the figure enables the measurement of a potential between the metal/metal oxide ring 30 (which is preferably a ruthenium metal ring having ruthenium oxide sputtered upon it or an iridium metal ring having iridium oxide sputtered upon it) and the Cu/CuSO₄ reference cell 4. As will be recognized to those skilled in the art, the actual measurement of this potential requires some type of a
30 meter (which is schematically represented by box 10 in the figure).

For reasons of convenience, it is preferred that the meter 10 be small enough to be hand held. The design, construction and use of such

meters encompasses a very broad range of alternatives which are well within the capabilities of persons skilled in the art.

Soil pH may then be calculated on the basis of the potential between the metal/metal oxide ring 30 and the reference cell 4, using procedures which are well-known and widely described in the open literature.

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ORP Potential

The preferred probe shown in the figure also facilitates the measurement of Oxidation/Reduction potential (ORP) (also sometimes referred to as redox potential).

This potential is measured between the metallic ring 3 (which is preferably Pt) and the reference cell 4. The hand-held meter 10 is used to make this measurement.

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Pipe to Soil Potential

The present soil probe is particularly useful for measuring soil properties in the vicinity of pipelines such as natural gas or oil pipelines.

As will be known to those skilled in the art, such pipelines are often fitted with wire leads to facilitate testing. In such circumstances, it is possible to utilize the present probe to measure the pipe to soil potential, as explained below.

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Firstly, the probe shown in the figure is inserted in the soil in the vicinity of the pipeline. The wire lead from the pipeline is then connected to

the meter 10, and the meter 10 is also connected to the probe. This allows a measurement of the pipe to soil potential against the reference cell 4.

The above descriptions will enable a person skilled in the art to use the probe of this invention to make measurements which describe soil resistivity, ORP, pH, temperature and pipe to soil potential. Preferred procedures to obtain these data, and procedures to interpret these data, are described in the Example below.

EXAMPLE

The preferred probe is attached to a steel shaft (40 in the figure) for field use. Measurement of redox potential, pH, temperature and pipe to soil potential all involve passive potential measurements with respect to the copper/copper sulfate reference electrode. Soil resistivity is measured using an AC potential drop technique with an AC signal of 1 kHz, which provides a local resistivity value at probe depth.

In the field, the probe is pushed to the desired depth by hand. In most locations a guide hole is made using a pipe locating rod or auger so that only the tip of the instrumented probe need be inserted into undisturbed soil.

Data were obtained using the probe shown in the figure at three separate locations in Western Canada, and are presented in Tables 1, 2 and 3. Data in Table 1 were collected at sites in British Columbia, the

data in Table 2 are from sites in Alberta and data in Table 3 are from sites in southwest Saskatchewan.

The redox potential data presented in these tables have been corrected for pH and the reference cell potential using the equation:

$$E_H = E_P + 0.3V + 0.050 (\text{pH}-7)$$

10 where E_H is the redox potential (NHE) and E_P is the potential measured using the probe with respect to the copper/copper sulfate electrode. Where soil pH was not determined, redox potential values are reported with respect to the copper/copper sulfate reference electrode.

Temperature

20 Temperature readings from the soil probe can be used to map temperature profiles around a gas transmission pipeline. Compression of the gas leads to elevated temperatures, with the pipe being warmer than the soil in the right of way (ROW). In Table 1, data obtained at location 6 were recorded at a distance of 6.2 m from the pipe. At this location the soil temperature was measured at 11.5°C at pipe depth. Closer to the pipe, temperatures up to 23°C were recorded. Table 2 indicates that the observed soil temperature falls the greater the distance traveled by the gas. 30 Site 2 was 32 km downstream of site 1. The temperature fell from 26.4°C at site 1 to 20.9°C at site 2.

Soil Resistivity

The soil probe is equipped with four metal rings which are used as electrodes for local four point resistivity measurement. Because the spacing of these rings is preferably only a few centimeters apart the resistivity measured is for the soil immediately surrounding the probe.

10 Both soil resistivity and the oxidation reduction potential (ORP) readings can change markedly between unsaturated and waterlogged soil. These readings can be used to find the top of the local water table around the pipe. In Table 1, shallow readings (70 and 64 cm depth) at locations 1 and 2 respectively, gave very high soil resistivity measurements (28 600 and 49 800 ohm cm) as well as relatively high ORP readings. These data are consistent with an unsaturated soil which
20 has gas as the continuous phase in the pore spaces between soil grains. This results in poor electrical conductivity and allows oxygen penetration and exchange with the overlying air. In contrast, deeper measurements (117 and 98 cm) gave lower resistivity readings (3780 and 3880 ohm cm) and more negative ORP's indicating more anaerobic conditions. The resistivities in the saturated zone converted to conductivities (0.02 to
30 0.3 mS/cm) agree well with values obtained for local groundwater samples taken at the same location (0.09 to 0.20 mS/cm). Resistivity measurements at a depth of 80 cm at location 3 (Table 1) were 7,440 ohm cm. Taken together, these resistivity measurements indicate that the top

of the saturated zone at sites 1 and 2 was between 70 and 80 cm depth at the time of the survey.

10 Data presented in Table 3 were obtained on a pipeline in Saskatchewan over a distance of approximately 250 meters. Readings were recorded every 16 meters. Readings 11 and 14 were obtained at the base of a small hill, whereas readings 12 and 13 were recorded at the top of the same hill. The resistivity values obtained at the base of the hill are lower than those obtained closer to the top. This is attributed to better drainage and lower water saturation for hill top soil. Readings 3 to 10 of Table 3 were recorded in a low area where dried white salts were
20 observed on the soil surface. A low soil resistivity measurement at a depth of 1.7 m indicates a subsurface salt seep near where reading 7 was taken.

Soil resistivity measurements made at locations in Alberta (Table 2) were consistent with values of conductivity for ground water samples taken at the same locations.

30 Soil resistivities are normally measured in undisturbed soil along the edge of right of ways by a standard "Wenner four pin measurement". In this prior art method, four metal pins arranged in a line, are pushed a few centimeters into the soil. A pin spacing of 1.5 m obtains a resistivity reading which is based on the cumulative properties of the soil to a depth of about 1.5 m. Wenner four pin resistivity values obtained at the site

described by the data in Table 1 (17 000 to 25 000 ohm cm) therefore represent a blend of saturated and unsaturated soil resistivities. This is consistent with the local soil probe readings for these zones being lower in the saturated zone and higher in the unsaturated zone than those given by the standard four pin method.

10 Pipelines are often protected by means of a dual system of coatings and cathodic protection. Many pipelines are coated with insulating polyolefin tape. The impressed current cathodic protection system is intended to protect the exposed steel should coating defects occur. However, when polyolefin tapes disbond they form a barrier which shields the cathodic protection current from the pipe surface. Jack *et al* have determined how far cathodic protection currents can penetrate under
20 a disbonded coating as a function of the conductivity of water trapped under the disbonded coating (ref: T.R. Jack, G. Van Boven, M. Wilmott, R.L. Sutherby and R.G. Worthingham, 1994, *Cathodic Protection Potential Penetration under Disbonded Pipeline Coating*, Materials Performance, **33** (8): 17 - 21). The local resistivity values obtained with the soil probe can therefore be used directly to determine how effective cathodic
30 protection will be for a tape coated pipeline in a given soil environment if disbondment of the tape occurs.

Soil Redox Potential (ORP)

ORP readings indicate how reduced or oxidized the environment surrounding the tip of the soil probe is. In most soil environments, the ORP reflects the balance between the rate of oxygen entry and the rate of its consumption by biological or chemical processes. In an unsaturated zone near the surface of the soil, the continuous phase between the soil particles is gas. In this case, diffusion of oxygen from the overlying air results in positive ORP readings (Table 1, locations 1 and 2, sites 1). In the underlying soil zone saturated with water, oxygen arrival is limited by its solubility in water and the rate of diffusion. Where the rate of uptake of oxygen exceeds the rate of its arrival, ORP readings drop to negative values corresponding to a reducing environment more or less free of oxygen. The aerobic/anaerobic interface coincides with the height of the local water table in such a site as noted in the discussion of resistivity above. Based on ORP data, this appears to be around 70 cm below surface in the site documented in Table 1. This is consistent with the conclusion based on resistivity measurements. Another example of reduced water saturation being evident in the ORP readings can be seen in readings 12 and 13, Table 3. Readings at a depth of 1.7 m under a small hill on the right of way indicate that the soil is drained more effectively than the surrounding less elevated area. This interpretation is supported by the increased soil resistivity for these two readings.

Because the rate of oxygen ingress and the rate of oxygen consumption determine the steady state oxygen concentration in a soil matrix, ORP readings are also influenced by the soil type and permeability.

10 Soil analyses for selected locations probed in Table 1 are given in Table 4. An ORP reading of -600 mV (NHE), taken at a depth of 1.2 m in a highly impermeable clay sediment, under a standing pool of water at the edge of the right of way, indicates very reduced, highly anaerobic conditions (Table 1, location 6). Soil analysis shows that this soil was rich in clay and plagioclase but had less sand content than other locations showing less negative ORP values (Table 4). The sediment in location 6 appeared to be impermeable, had the consistency of a modeling clay and
20 the dark gray color characteristic of anaerobic environments.

Implications for Corrosion

Previous studies have attempted, with some success, to correlate soil properties with the corrosion of exposed unprotected steel. Soil probes have been described specifically for this purpose.

30 In the above referenced Booth *et al.* papers, a procedure is reported to identify aggressive and non-aggressive soils based on ORP and resistivity readings. Aggressive soils were those having an ORP of less than 400 mV (NHE) for non-clay soils or 430 mV (NHE) for clay soils or a resistivity of less than 2000 ohm cm. In borderline cases, water

content was used to designate a site. Levels greater than 20% were deemed aggressive. In Booth *et al.*'s definitions, clay soils are those having a fine particle size and low permeability, rather than those having a substantial fraction of clay minerals present. These factors were used to correctly identify the probability of severe corrosion in 81 of the 87 sites considered. The prior referenced Starkey and Wight paper describes a finer scale of gradations for soil aggressivity. Based on ORP readings, their scheme placed increasingly aggressive soil in the following sequence:

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ORP (NHE)	Anticipated Corrosion
• Below 100 mV	severe corrosion
• 100 to 200 mV	moderate corrosion
• 200 to 400 mV	slight corrosion
• Over 400 mV	no corrosion

Field observations reported here can be correlated to the corrosion seen on unprotected steel coupons located at the sites where probe readings were made. These observations are not consistent with the parameters established by Booth *et al.*

30

Based on the criteria of Booth *et al.*, all the sites documented in this study have aggressive soil conditions at depths over 1 m. ORP readings are <400 mV (NHE) except for readings 12 and 13 in Table 3, where high values of ORP were obtained in the well drained soil at a small hill. Given

that all the sites reported in this study were locations having wet soil conditions, the prevalence of anaerobic conditions (i.e. aggressive conditions) is not surprising. Resistivities give mixed results in terms of predicted soil aggressivity but only reading 12, Table 3 shows resistivity above 2000 ohm cm with a correspondingly benign ORP reading. This is the only location which would be deemed non-aggressive according to the criteria in the Booth *et al.* references.

Corrosion data are available for some of the sites described here based on observation of the pitting and thinning of unprotected steel coupons installed during construction of the pipeline. Corrosion was found to be negligible in the site described in Table 1 despite ORP readings generally less than 400 mV (NHE) and groundwater pH less than 6. Resistivities were in excess of 2000 ohm cm consistent with a non aggressive designation. Corrosion was also insignificant in the organic soil of site 1, Table 2, despite ORP readings less than 400 mV (NHE) and resistivities less than 2000 ohm cm. Site 2, Table 2, showed significant corrosion consistent with an aggressive designation. Predictions based on earlier work apparently require some caution. All wet sites will be designated aggressive on the basis of ORP, yet two of the three sites for which corrosion information exists fail to match the simple aggressive/non aggressive designations predicted by the method of Booth *et al.* The

criteria in the Starkey and Wight reference provide a better fit in these cases predicting slight to moderate corrosion.

Uses of the Probe

10 Although the probe was designed specifically to characterize
corrosive soil environments for gas transmission pipeline right of ways the
use of the probe is not limited to this. For example the probe can be used
to select sites for further investigation in stress corrosion cracking (SCC)
field studies. To develop correlations between site characteristics and the
chance of environmental cracking on line pipe, extensive excavation
programs must be conducted. This process is well established for stress
corrosion cracking sites based on very extensive exploratory excavation
programs conducted largely by Trans Canada Pipelines Ltd. (ref:
20 B. Delanty and J. O'Beirne, *Major Field Study Compares Pipeline SCC
with Coatings*, Oil & Gas Journal, 39-44, June 1992). The soil probe has
a possible role for targeting excavation sites within a selected location.
Soil characteristics at pipe depth can now be added to information on site
topography, soil type and drainage in the selection process.

30 Subsurface resistivity measurements by the soil probe can define
the saline zone and the degree of upward migration at past or future
pipeline construction sites. This would avoid more time consuming and
expensive sampling programs. A subsurface saline seep was identified at
the site described in Table 3 as being quite localized at pipe depth

compared to surface indications. Focusing special excavation practices to control salt migration at the source of the seep could save time and money in construction.

10 As well as applications for pipeline operations the soil probe has applications in environmental areas. The aerobic/anaerobic nature of a site can determine the rate and extent of natural or accelerated remediation, especially for hydrocarbon contaminated soils. Monitoring the ORP and temperature by soil probe may be a way to observe the conditions and process of remediation in the field.

20 Thus, the soil probe described herein has been used in a number of field locations. Results indicate that the probe can provide insight into conditions at pipe depth. In summary, the present probe may be used for the following purposes:

- Temperature measurements can profile heat loss around pipelines.
- ORP and resistivity readings can predict soil aggressivity.
- Resistivity readings can determine the extent of cathodic protection under disbonded coatings.
- Correlations between soil probe measurements and ILI based excavations may allow targeted investigation and remedial action on pipelines not accessible to ILI.
- Detailed soil measurements augment surface characteristics now used to select sites for excavation in SCC field programs.

- Probe measurements can monitor salt movement and remediation processes in soil.

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Table 1: Soil Probe Measurements Made At Locations in British Columbia							
Location	Site #	Resistivity (Ω cm)	ORP (mV) (Cu/CuSO ₄)	ORP (mV) (NHE)	Depth (m)	T (° C)	Soil pH
1	1	28,600	-230	+5	0.70	18	5.4-5.9
1	2	3,780	-495	-248	1.17	23	5.4-6.1
2	1	49,800	+170	+470	0.64	17	
2	2	3,880	-510	-210	0.98	18	
3	1	7,440	-621	-362	0.80	17	5.4-6.3
3	2	2,260	-400	-171	1.74	20	5.8
4	1	4,460	-160	+140	1.67	21	
4	2	4,020	-462	-209	1.67	22	5.6-6.2
5	1	3,520	-207	+93	1.90	18	
5	2	3,880	-430	-189	1.55	18	5.5-6.0
6	1	2,700	-820	-591	1.20	11.5	5.6-5.8

Table 2: Soil Probe Measurements Made At Locations In Alberta							
Site #	Location	Resistivity (Ω cm)	Conductivity (mS/cm)	ORP (mV) (Cu/CuSO ₄)	T (° C)	Ground Water Conductivity (mS/cm)	Ground Water pH
1	Top of pipe	401	2.5	-208	26.4		
1	Beside Pipe	670	1.5	-1.99	24.8	1.0-1.6	6.0-7.0
2	Top of Pipe	730	1.4	-623	20.9		
2	Beside Pipe	680	1.5	-612	19.1	1.1-1.4	6.4-7.3

Table 3: Soil Probe Measurements Made At A Location in South West Saskatchewan, Canada.

Reading #	Measurement Interval Along ROW (m)	Resistivity (Ω cm)	T ($^{\circ}$ C)	ORP (mV) (Cu/CuSO ₄)	Depth (m)
1	484.0	2149	8.3	-670	1.50
2	503.7	1928	11.1	-255	1.20
3	516.5	2084	7.9	-575	1.50
4	532.8	1176	9.6	-683	1.50
5	548.9	798	9.8	-610	1.65
6	568.2	367	10.0	-658	1.65
7	576.6	210	11.8	-509	1.65
8	592.4	840	11.9	-570	1.65
9	608.4	342	11.6	-425	1.65
10	624.1	631	12.5	-600	1.70
11	640.1	756	11.5	-90	1.70
12	656.3	2550	10.7	171	1.70
13	672.5	1260	11.4	161	1.70
14	688.7	840	12.1	-147	1.70
15	704.5	980	12.8	-437	1.70

Table 4: Mineral Composition of Soils From British Columbia Sites Described in Table 1

DESCRIPTION	LOCATION 1 ¹	LOCATION 4 ¹	LOCATION 6 ¹
QUARTZ ²	53	54	40
PLAGIOCLASE	17	15	26
KFELDSPAR	0	0	0
CALCITE ³	1	1	2
DOLOMITE ³	0	0	0
KAOLINITE ⁴	2	2	2
ILLITE ⁴	27	28	30

1. See Table 1
2. Sand
3. Limestone
4. Clay Minerals.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A soil probe comprising:

an elongate housing having a longitudinal length;

first, second, third, and fourth metallic rings mounted over the housing, the metallic rings being spaced along the length, respectively;

wherein the first and fourth metallic rings receive an input voltage applied therebetween; and,

10 wherein the second and third metallic rings access an output voltage therebetween for comparing to the input voltage to determine a resistivity of a soil into which the probe is inserted.

2. The soil probe of claim 1 wherein the housing is at least one of cylindrical and hollow.

3. The soil probe of claim 2 wherein the metallic rings are cylindrical, the metallic rings each having an inner diameter approximating an outer diameter of the housing.

4. The soil probe of claim 1 wherein the input voltage is an alternating current (AC) voltage.

5. The soil probe of claim 1 and further comprising:

20 a reference cell formed in the housing for providing a reference voltage, the reference cell having an electrode in contact with an electrolyte, the electrolyte being in contact with a porous sample port, the porous sample port being in contact with the soil through at least one hole in the housing.

6. The soil probe of claim 5 and further comprising:

a fifth metallic ring mounted over the housing;

wherein the fifth metallic ring and the electrode access a second output voltage therebetween for determining, with the reference voltage, an oxidation/reduction potential of the soil.
7. The soil probe of claim 5 and further comprising:

a metal/metal oxide ring mounted over the housing;

wherein the metal/metal oxide ring and the electrode access a third output voltage therebetween for determining, with the reference voltage, a pH level of the soil.
- 10 8. The soil probe of claim 1 and further comprising a thermistor located in the housing for measuring soil temperature.
9. The soil probe of claim 1 wherein the housing is formed from a non-conducting material.
10. The soil probe of claim 1 wherein the first, second, third, and fourth metallic rings are formed from at least one of stainless steel and platinum.
11. The soil probe of claim 5 wherein the electrode is a copper electrode and the electrolyte is a copper sulphate electrolyte.
12. The soil probe of claim 5 wherein the porous sample port is formed from a porous ceramic.
13. The soil probe of claim 6 wherein the fifth metallic ring is formed from platinum.
- 20 14. The soil probe of claim 7 wherein the metal/metal oxide is at least one of ruthenium/ruthenium oxide and iridium/iridium oxide.
15. The soil probe of claim 1 and further comprising a pointed tip at one end of the housing for penetrating the soil.

16. A soil probe comprising:
 - an elongate housing having a longitudinal length for inserting into a soil;
 - a reference cell formed in the housing for providing a reference voltage, the reference cell having an electrode in contact with an electrolyte, the electrolyte being in contact with a porous sample port, the porous sample port being in contact with the soil through at least one hole in the housing; and,
 - a metallic ring mounted over the housing;
 - wherein the metallic ring and the electrode access an output voltage therebetween for determining, with the reference voltage, an oxidation/reduction potential of the soil.
17. The soil probe of claim 16 wherein the housing is at least one of cylindrical and hollow.
18. The soil probe of claim 16 wherein the metallic ring is cylindrical, the metallic ring having an inner diameter approximating an outer diameter of the housing.
19. The soil probe of claim 16 wherein the housing is formed from a non-conducting material.
20. The soil probe of claim 16 wherein the electrode is a copper electrode and the electrolyte is a copper sulphate electrolyte.
21. The soil probe of claim 16 wherein the porous sample port is formed from a porous ceramic.
22. The soil probe of claim 16 wherein the metallic ring is formed from platinum.
23. The soil probe of claim 16 and further comprising a pointed tip at one end of the housing for penetrating the soil.

24. A soil probe comprising:
- an elongate housing having a longitudinal length for inserting into a soil;
- a reference cell formed in the housing for providing a reference voltage, the reference cell having an electrode in contact with an electrolyte, the electrolyte being in contact with a porous sample port, the porous sample port being in contact with the soil through at least one hole in the housing; and,
- a metal/metal oxide ring mounted over the housing;
- wherein the metal/metal oxide ring and the electrode access an output voltage therebetween for determining, with the reference voltage, a pH level of the soil.
- 10 25. The soil probe of claim 24 wherein the housing is at least one of cylindrical and hollow.
26. The soil probe of claim 24 wherein the metal/metal oxide ring is cylindrical, the metal/metal oxide ring having an inner diameter approximating an outer diameter of the housing.
27. The soil probe of claim 24 wherein the housing is formed from a non-conducting material.
28. The soil probe of claim 24 wherein the electrode is a copper electrode and the electrolyte is a copper sulphate electrolyte.
29. The soil probe of claim 24 wherein the porous sample port is formed from a porous ceramic.
30. The soil probe of claim 24 wherein the metal/metal oxide is at least one of
20 ruthenium/ruthenium oxide and iridium/iridium oxide.
31. The soil probe of claim 24 and further comprising a pointed tip at one end of the housing for penetrating the soil.

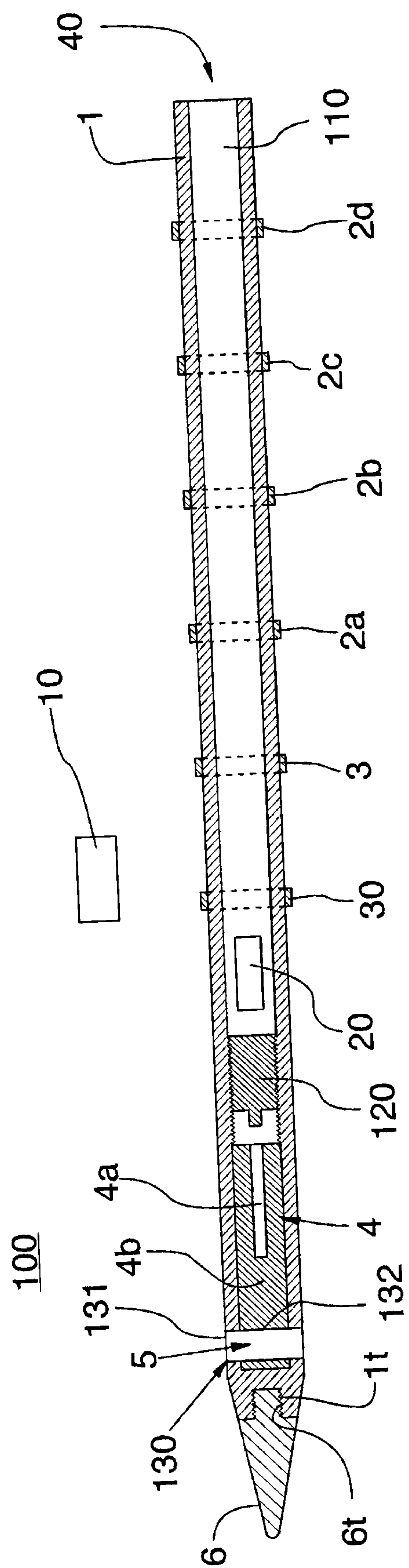


Figure 1

