

STATE-OF-CHARGE INDICATOR AND METHOD THEREFOR FOR A FLOODED CELL BATTERY

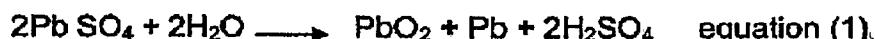
FIELD OF INVENTION

The present invention relates to flooded cell batteries. In particular, the present invention relates to the determination of the state of charge of a flooded cell battery. In one form, the present invention relates to the determination of the state of charge via specific gravity of the electrolyte within a flooded cell battery.

BACKGROUND ART

There are two main techniques used to measure the state-of-charge of lead-acid cells. The first technique measures the specific gravity of the electrolyte, and the second technique uses some electrical property of the cell.

The method of the first technique relies on the fact that the specific gravity of the electrolyte changes as the cell is charged or discharged. The specific gravity is basically a measure of the concentration of sulphuric acid. The overall electrochemical reaction of a flooded lead-acid cell battery during charging is



and during discharging is



Equation (1) and (2) indicate that during charging, the concentration of the sulphuric acid increases, and during discharging it decreases. The specific gravity of a battery cell in operation, for example in a marine environment, varies from approximately 1.05 for a fully discharged cell to approximately 1.3 for a fully charged cell.

One method used in measuring via the first technique utilises a vapour pressuring probe. This relies on the fact that the vapour pressure of water above the electrolyte depends upon the concentration of the acid, and hence the specific gravity of the electrolyte. Thus the vapour pressure of the water determined by a relative humidity sensor may be used as a measure of the state-of-charge of the cell. One problem identified by the inventors was the time taken for the sensor to reach steady state measurement equilibrium, which was from 3 to 30 minutes.

The specific gravity of the sulphuric acid electrolyte in a flooded lead-acid cell is has been identified by the inventors as an important parameter that may be

used to determine the state of charge for traction applications, including submarine cells. It is a difficult parameter to measure because of the highly corrosive nature of the electrolytic environment. For example, in a diesel-electric submarine, the specific gravity has been measured in the past manually by floatation means using a hydrometer.

Any discussion of documents, devices, acts or knowledge in this specification is included to explain the context of the invention. It should not be taken as an admission that any of the material forms a part of the prior art base or the common general knowledge in the relevant art in Australia or elsewhere on or before the priority date of the disclosure and claims herein.

An object of the present invention is to provide an apparatus and method for measuring specific gravity of a flooded cell battery.

A further object of the present invention is to alleviate at least one disadvantage associated with the prior art.

15 SUMMARY OF INVENTION

The present invention provides, in one aspect of invention, a method of and/or apparatus for measuring and/or calculating specific gravity of a flooded cell battery, comprising measuring humidity in the cell and compensating the measured humidity for temperature.

The present invention provides, in another aspect of invention, a method of and/or apparatus for calculating the specific gravity of a flooded cell battery, using a humidity sensor comprising calculating, in accordance with a quadratic equation, the specific gravity based on sensor output, and compensating the calculation, for temperature, in accordance with a linear relationship between specific gravity and temperature.

The present invention provides, in a further aspect of invention, a method of and/or apparatus for measuring specific gravity of a flooded cell battery having electrolyte fluid therein, comprising a humidity measuring means adapted to measure humidity in the cell, and logic means adapted to provide compensation for the measured humidity based on temperature.

The present invention provides, in a still further aspect of invention, a method of and/or apparatus for determining the specific gravity of a flooded cell battery, using a humidity sensor, comprising logic means adapted to determine

the specific gravity based on sensor output, in accordance with a quadratic equation, and further wherein the logic means is adapted to compensate the specific gravity determination, for temperature, in accordance with a linear relationship between specific gravity and temperature.

- 5 The sensor may have a membrane permeable to water vapour, but not to bulk liquid, such as porous polytetrafluoroethylene (PTFE)

The present invention also provides, in yet another aspect, in combination, a flooded cell battery and an apparatus as disclosed herein.

- 10 In one embodiment, Specific Gravity is assessed with regard to vapour pressure and temperature. In another embodiment, Specific Gravity is assessed with regard to temperature and relative humidity. In still another embodiment, the specific gravity is determined in accordance with any one of equations 3, 4, or 5 substantially as disclosed herein.

- 15 Other aspects and preferred aspects are disclosed in the specification and/or defined in the appended claims, forming a part of the description of the invention.

- 20 In essence, the present invention comes about as the inventors have realised that there is a quadratic relationship between specific gravity and sensor output, and a linear relationship between specific gravity and temperature. Furthermore, using a membrane which is relatively permeable to water vapour, but not bulk liquid, enhances the lifespan and accuracy of the measurement of the specific gravity.

- 25 The present invention has been found to result in a number of advantages, such as the continuous and non manual determination of the specific gravity of sulphuric acid in a flooded cell without the use of fluid pumps or other equipment with moving parts.

- 30 Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Further disclosure, objects, advantages and aspects of the present application may be better understood by those skilled in the relevant art by reference to the following description of preferred embodiments taken in conjunction with the accompanying drawings, which are given by way of illustration only, and thus are not limitative of the present invention, and in which:

Figure 1 illustrates a sensor in accordance with one aspect of the present invention, and

Figure 2 illustrates a relationship between specific gravity, temperature and sensor output.

DETAILED DESCRIPTION

Future improvements to the prototype sensor are depicted in Figure 1.

Referring to Figure 1, which shows the sensor 1 in accordance with one aspect of the present invention, with a 'cut-away' showing a number of various components, the sensor employs a commercially available humidity sensor 2 powered by a 5V voltage regulator supplied from a 9V battery or a mains derived regulated power supply 3. The sensor 2 is a capacitive type integrated circuit based humidity sensor such as a Honeywell HIH-3610 or a Sensiron SHT75 which also incorporates a temperature sensing element 3. The use of a battery supply 9 was found to substantially eliminate electrical noise in the supply to the sensor. The sensor is located within a glass or polyvinylchloride (PVC) tube 4 of approximate length 150 mm by 15 mm inside diameter, and in the lower end 5 of the tube there is provided a membrane 6 which is relatively permeable to water vapour, but not to bulk liquid, such as a PTFE membrane, of diameter 15 mm and thickness 20 μm . The membrane 6 is preferably reinforced on the inside with a polypropylene or PTFE mesh (not shown) to provide mechanical strength and is attached to the tube end 5 with a silicone rubber sealant or a PVC compressive cap.

In essence, the sensor 2 measures the humidity above the electrolyte which depended upon the state of charge of the flooded cell. This is because water is produced during the discharge and consumed during the recharge of the cell. During discharge, the water content of the electrolyte rises and causes a

corresponding increase in the surface water vapour, i.e. humidity. Conversely, the humidity above the electrolyte decreases as the cell is charged.

To measure the specific gravity of the acid, the glass or PVC tube 4 is preferably immersed in the electrolyte to no particular depth – all that is required is that the PTFE membrane is below the surface of the electrolyte. In an alternative arrangement, the membrane 6 may be omitted and the sensor located above the surface of the liquid provided a vapour conduit which substantially excludes ambient moisture is employed. In the embodiment shown, the membrane 6 allows water vapour to pass into the lower chamber 5 of the tube, and allows the sensor 2 to measure the humidity. It has also been found to exclude acid aerosols from the sensor 2 and diminished turbulent effects caused by rising air bubbles used for agitation of the electrolyte.

As noted above, the tube length is divided into two chambers and the sensor 2 is housed in the lower chamber 5. The upper chamber 7 houses a microprocessor 8, and if required a temperature sensor 3. Humidity and temperature data are inputted to the microprocessor 8 to derive the specific gravity. The internal dimensions of the lower chamber 5 may be minimized to reduce the air volume and so speed up the response rate of the humidity sensor.

In testing the present invention, the sensor 1 of the present invention was tested in electrolytes with specific gravities over the range from 1.100 to 1.300 and temperatures of 10, 20, 30.2 and 40°C. Plots of specific gravity of as a function of sensor output at different temperatures are shown in Figure 2. This is actually represented/ displayed as a 3-dimensional surface plot.

Essentially, in accordance with one aspect of invention, it has been found that there is a quadratic relationship between specific gravity and sensor output at each temperature tested, and a linear relationship between specific gravity and temperature for constant pressure.

At a temperature of 20°C and specific gravity of 1.2, the slope of the line is approximately 5 mV per 0.001 units of specific gravity, which means that changes of 0.001 units of specific gravity can be monitored if the output is fed into a 12-bit ADC (Analogue to Digital Converter). This is because a 12-bit ADC has been found to have a resolution of approximately 1 mV. In operation, the specific gravity of a submarine cell, for example, covers the approximate range from

1.120 to 1.300, i.e. -.180 units of specific gravity, and so changes of approximately 0.5% in the state of charge can be measured. This is considered adequate for the practical application to a submarine cell.

An empirical relationship has been developed in another aspect of invention, and expresses the specific gravity S in terms of vapour pressure P (in sensor output Volts) and temperature T (in °C).

For example, with the Honeywell HIH-3610 humidity sensor

$$S = C_0 + C_1.T + C_2.P + C_3.T^2 + C_4.P^2 \quad \text{equation (3)}$$

where

$$\begin{aligned} C_0 &= 1.183, \\ C_1 &= 1.659 \times 10^{-3}, \\ C_2 &= 1.926 \times 10^{-1}, \\ C_3 &= -2.505 \times 10^{-6}, \text{ and} \\ C_4 &= -6.434 \times 10^{-2} \end{aligned}$$

Since $C_3 \approx 0$, equation (1) simplifies to

$$S = C_0 + C_1.T + C_2.P + C_4.P^2 \quad \text{equation (4)}$$

In the case of the Sensiron SHT75 humidity sensor which has basic outputs of temperature in degrees centigrade (°C) and relative humidity (% RH) in a digital form and which may be readily interfaced to a microprocessor such as a PIC 16F876, it has been found that the invention when tested in electrolytes over the specific gravity range of 1.07 to 1.30 and at temperatures of 10, 20, 30, 40 and 50 °C, that an empirical relationship which involves cubic terms of both temperature and relative humidity was developed and is given by :-

$$SG = C_5 + C_6.RH + C_7.T + C_8.RH^2 + C_9.T^2 + C_{10}.RH^3 + C_{11}.T^3 \quad \text{equation (5)}$$

where

$$\begin{aligned} C_5 &= 1.2722 \\ C_6 &= 4.8507 \times 10^{-3} \\ C_7 &= 5.6716 \times 10^{-4} \\ C_8 &= -8.4910 \times 10^{-5} \\ C_9 &= -2.6833 \times 10^{-5} \\ C_{10} &= 1.3363 \times 10^{-7} \end{aligned}$$

$$C_{11} = 4.0548 \times 10^{-7}$$

Another aspect of invention determined by the present inventors is the effect of cell agitation on the sensor. The sensor was immersed in electrolyte of specific gravity 1.300, and the sensor's output was monitored with and without electrolyte agitation using nitrogen bubbles rising onto the lower end of the sensor. The nitrogen flow was approximately 200 ml/minutes and caused significant turbulence in the electrolyte. No significant change in the sensor's output was observed, and hence the agitation did not affect the performance of the sensor.

Another aspect of invention determined by the present inventors is the effect of using different sensor depths. This was investigated by changing the immersed depth of the sensor into an electrolyte of specific gravity 1.300. A sensor was constructed using a glass tube of approximate length 400 mm and diameter 15 mm. The lower end of the sensor was immersed 35 and 385 mm below the surface of the electrolyte, and the output of the sensor monitored. The change in depth of 350 mm was found to have an insignificant effect on the operation of the sensor.

A prototype specific gravity sensor has been developed and its design has been shown to be robust to acid attack by the electrolyte of a flooded cell. It has been tested over the specific gravity range of 1.120 to 1.300, and temperature from 10 to 40°C, and demonstrated to be accurate within 2%. No significant effect was observed for cell agitation, or immersion depth on the sensor's output.

While this invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification(s). This application is intended to cover any variations uses or adaptations of the invention following in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice within the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth.

As the present invention may be embodied in several forms without departing from the spirit of the essential characteristics of the invention, it should be understood that the above described embodiments are not to limit the present

invention unless otherwise specified, but rather should be construed broadly within the spirit and scope of the invention as defined in the appended claims. Various modifications and equivalent arrangements are intended to be included within the spirit and scope of the invention and appended claims. Therefore, the

5 specific embodiments are to be understood to be illustrative of the many ways in which the principles of the present invention may be practiced. In the following claims, means-plus-function clauses are intended to cover structures as performing the defined function and not only structural equivalents, but also equivalent structures. For example, although a nail and a screw may not be

10 structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface to secure wooden parts together, in the environment of fastening wooden parts, a nail and a screw are equivalent structures.

"Comprises/comprising" when used in this specification is taken to specify

15 the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof."

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of measuring specific gravity of a flooded cell battery having electrolyte fluid therein, comprising the steps of:
 - 5 measuring humidity in the cell, and
 - compensating the measured humidity for temperature.
2. A method of calculating the specific gravity of a flooded cell battery, using a humidity sensor, the method comprising the steps of:
 - 10 calculating, in accordance with a quadratic equation, the specific gravity based on sensor output, and
 - compensating the calculation, for temperature, in accordance with a linear relationship between specific gravity and temperature.
- 15 3. A method as claimed in claim 2, wherein the method is substantially applied in accordance with the algorithm:

$$S = C0 + C1.T + C2.P + C3.T^2 + C4P^2 \quad \text{equation (3)}$$
 where
 - 20 C0 = 1.183,
 - C1 = 1.659×10^{-3} ,
 - C2 = 1.926×10^{-1} ,
 - C3 = -2.505×10^{-6} , and
 - C4 = -6.434×10^{-2}
- 25 4. A method as claimed in claim 2, wherein the method is substantially applied in accordance with the algorithm:

$$S = C0 + C1.T + C2.P + C4.P^2 \quad \text{equation (4)}$$
 where
 - 30 C0 = 1.183,
 - C1 = 1.659×10^{-3} ,
 - C2 = 1.926×10^{-1} , and
 - C4 = -6.434×10^{-2}

5. A method as claimed in claim 2, wherein the method is substantially applied in accordance with the algorithm:

$$SG = C5 + C6.RH + C7.T + C8 RH^2 + C9 T^2 + C10 RH^3 + C11.T^3 \quad \text{equation (5)}$$

where

5 $C5 = 1.2722$

$$C6 = 4.8507 \times 10^{-3}$$

$$C7 = 5.6716 \times 10^{-4}$$

$$C8 = - 8.4910 \times 10^{-5}$$

$$C9 = - 2.6833 \times 10^{-5}$$

10 $C10 = 1.3363 \times 10^{-7}$

$$C11 = 4.0548 \times 10^{-7}$$

6. Apparatus adapted to measure specific gravity of a flooded cell battery having electrolyte fluid therein, comprising:

15 a humidity measuring means adapted to measure humidity in the cell, and logic means adapted to provide compensation for the measured humidity based on temperature.

7. Apparatus adapted to determine the specific gravity of a flooded cell battery, using a humidity sensor, comprising:

20 logic means adapted to determine the specific gravity based on sensor output, in accordance with a quadratic equation, and further wherein the logic means is adapted to compensate the specific gravity determination, for temperature, in accordance with a linear relationship between specific gravity and temperature.

8. Apparatus as claimed in claim 6 or 7, wherein the specific gravity is determined in accordance with equation 3, 4, or 5 substantially as disclosed herein.

9. Apparatus adapted to determine the specific gravity of a flooded cell battery, using a humidity sensor, said apparatus including:

processor means adapted to operate in accordance with a predetermined instruction set,

5 said apparatus, in conjunction with said instruction set, being adapted to perform the method as claimed in any one of claims 1 to 5.

10. An apparatus as claimed in any one of claims 7 to 9, wherein the sensor has a membrane permeable to water vapour, but not to bulk liquid.

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11. An apparatus as claimed in claim 10, wherein the membrane is porous polytetrafluoroethylene (PTFE).

12. In combination, a flooded cell battery and the apparatus as claimed in any
15 one of claims 6 to 11.

13. A combination as claimed in claim 12, adapted for use in a marine environment.

20 14. A combination as claimed in claim 12 or 13, wherein the flooded cell battery is flooded cell battery used in a submarine.

15. A computer program product including:

25 a computer usable medium having computer readable program code and computer readable system code embodied on said medium for calculating the specific gravity of a flooded cell battery, within a data processing system; said computer program product including:

computer readable code within said computer usable medium for operating said system in accordance with any one of claims 1 to 5.

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