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Developing a Low-Cost Salinity Sensor Using Locally Sourced Materials

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***Abstract* - We report the design and construction of a locally constructed hydro-meteorological sensor for surface and underwater vehicles. This salinity sensor consists of four electronics units: the power, input (sensor), gain (amplifies the output signal), and output units. Each unit/block utilizes various low-power integrated circuits. The calibration equation of the salinity sensor was $1055.6\exp^{-1.062}$ ml/mg/volt (correlation coefficient r = 0.9897). The performance and the coefficient of efficiency of the constructed sensor were compared with a standard sensor, showing the Mean Bias Error (MBE), Root Mean Square Error, and Standard Deviation of -0.5535, 1.3825, and 3.4839 ml/mg, the error margins were relatively small, indicating an excellent performance by the sensor. However, the negative MBE suggests a slight underestimation of the standard. Conclusively, the sensor is efficient in hydro-meteorological studies, capable of monitoring solution conductivity and measuring salinity (and total dissolved salt) in the ocean or brackish water.**

Keywords: PVC, Braze rods (electrode), Light-Emitting Diode (LED), Salt, Digital multimeter and manual weighing scale.

I. INTRODUCTION

In 1865, Forchhammer introduced the term salinity, dedicating his research to determining individual components of sea salt rather than the total salinity. During his study, he discovered that the ratio of major components in seawater samples from various locations around the globe was constant. This constant ratio was later named Forchhammer's Principle of Constant Proportions [9]; [11] sequel to his studies at the end of the nineteenth century, William Dittmar experimented on several methods to analyze the chemical composition of seawater [18]. Thormas 2014 discovered that the Dittmar methods were much superior and extremely precise than others [7]; [14]. Through silver nitrate precipitation of the chloride content from sea water by adding a solution of silver nitrate to the aqueous solution of chloride ions, Dittmar determined the chloride content and verified the credibility of the process by comparing it with synthetic seawater [3]. He later analyzed seventy seven samples from around the world, taken during the Challenger Expedition. He gathered that although the salinity of the sea waters differs, the Forchhammer's Principle of Constant Proportions was exact [17]; [19].

Salinity determines the type of organisms and plants that can thrive in a water body. Any slight change in salinity can induce stress or death to the inhabiting organisms, thereby disrupting the local and broader ecosystems [12]; [10]. The salinity sources in freshwater include urban and rural runoff from industry, sewage, agriculture, and storm water. An increase in salinity levels can also end the existence of vegetation due to the rise in the water table.

The region within the tidal restriction of rivers that move into the sea experiences variation in salinity between lower and higher tides [16]; [13]. In discharge, there is usually a moderate variation in salinity, as freshwater entering the estuary from tributaries meets the seawater moving in from the ocean.

Human attempts to measure seawater saltiness originated in ancient Greece. However, the efficiency of the original methods was incipient, with low sensitivity and repeatability [1]. Later, more precise techniques were developed viz. evaporation [2], solvent extraction [4], and precipitation [5]; [15].

Several salinity meters were stand in the way of one another when placed in the same liquid. The degree of interference depends on several factors, including the combination of sensors used, the interface, etc. This design aims to solve the problem associated with the ocean salinity measurement sensor in marine research. Today, salinity sensors are very costly in the international market and it not easy to maintain when it is faulty.

II. METHODOLOGY

The salinity measurement was carried out in the Chemical Oceanography Laboratory of The Federal University of Technology, Akure, Nigeria. Thesalinity sensor designed measures the current flow in between the twobraze rods electrodes. The amount of current is proportional to the concentration of ions in thesolution. The measured current is proportional to the conductivity of the solution as the direct voltage is applied across the electrodes [8].

2.1 Electrical design

Two braze rods were used to transmit the salinity level to LED output indicators. The sensor measures conductance in the electrical system. When the saltwater has a resistance equal to the current that applied through the saltwater and resistors, it causes the differential voltage across the input, and the comparator circuit is used by an op-amp IC, the LED Display Level Meters.

The output voltage must be close to zero when salt content is not detectable., i.e., the design sensor should perform as a salinity measuring device rather than a pH-sensing device. Thus, the salinity sensor consists of two 40 mm length, differential amplifiers, about 5 mm apart, and a 2.5 V_{ref} reference. At the non-inverting input of the differential amplifier, an alternator resistance was inserted in water, R_1, $R_{2,}$ and R_3, (1). The voltage developed across R_3 when compared with voltage constant set at inverting input of the amplifier. Pot V_{R1} calibrates the salinity level. R_4 and R_3 obtain the amplified gain can be 5 volts. The output voltage of the differential amplifier is shown in Figure 1 [6].

$$V_O = \frac{R_3}{R_4}(V_{non-inv} - V_{inv}) \qquad (1)$$

The digital electronic system for the salinity sensor is depicted in Figure 1.

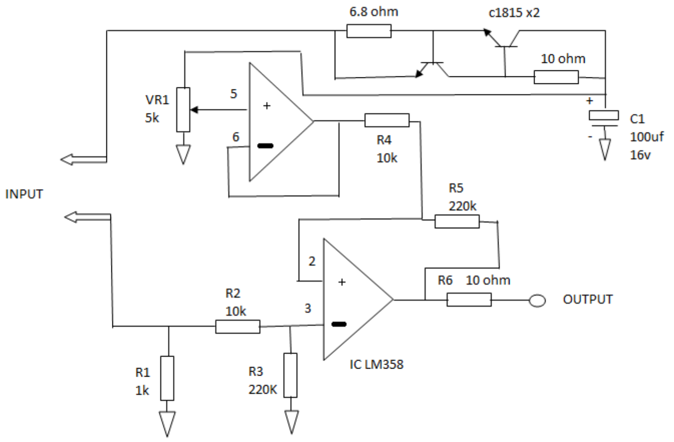

Figure 1: A diagram showing the circuit design of the salinity sensor (Generated using PCB123 Electronic Design Software)

The power supply circuit provides 5 volts for the system using Linear Monolithic (LM) 7805. Due to the high sensitivity of digital devices to voltage, an internal DC power supply is used. The first element in the unit is a three-terminal adjustable regulator, bridge rectifier, used as a network of IN4007 diodes. Fluctuations and ripples superimposed on the rectifier DC voltage are filtered out by 220 µF, 25 V, and 0.1 µF capacitors, schematically shown in Figure 2.

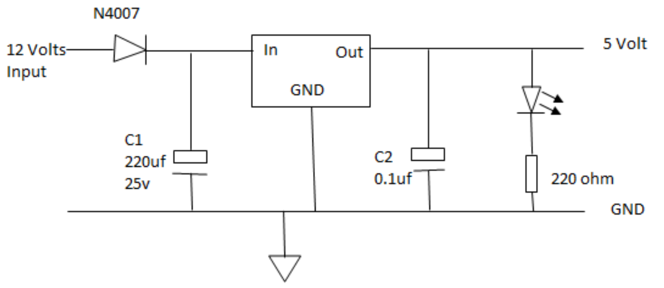

Figure 2: Power Supply Circuit Diagram

A 5-in-1 auto-ranging digital multimeter was used as an output display unit with a frequency measure of 0 to 20 volts.

2.2 Mechanical design

The PVC pipe was used for the sensor's body because of its low-cost and corrosion-resistant merits and the braze two rods used as sensing devices shows in Figure 3.

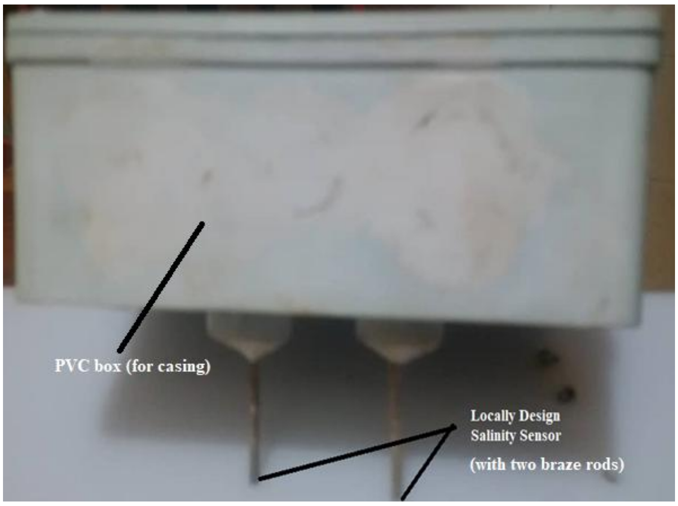

Figure 3: Designed Salinity Sensor

2.3 Calibration

The novel sensor was calibrated for accuracy and precision against a standard one at the Department of Physics, the Federal University of Technology Akure. Nigeria. (Figure 4). The following were the steps taken for the calibration of the new sensor.

1. The salinity sensor was inserted in ordinary (non-saline, reference) water. The RV1 was adjusted at differential output close to zero. The derived value at Figure 4 is

deducted from output measured after adding water of various salinities.

2. The standard salinity sensor and the newly fabricated one were used to measure the salinity of the water samples. Their respective salinity values are listed in Table 1. The relation and characteristic equation developed was program inside the micro-controlled.

The precision and accuracy of the developed sensor against the standard were computed after series of experiments and measurements (Figure 5).

The derived standard calibration curve is depicted in Figure 6.

Figure 4: Manual Weighing Balance with Salt at Physics Laboratory Department FUTA during the Design Salinity Sensor Calibration

Figure 5: Laboratory calibration of Design Salinity Sensor at Physics Department FUTA

Table 1: Turbidity calibration table

Volume of Water	**200 ml**	**375 ml**
Output Voltage (V)	Amount of salt (mg)	Volume of water/unit mass of salt (ml/mg)
0.47	0.07	2703
0.83	0.19	1075
1.13	0.23	885
1.57	0.30	658
1.76	0.35	568
2.24	0.41	490
2.34	0.47	427
3.00	0.60	333

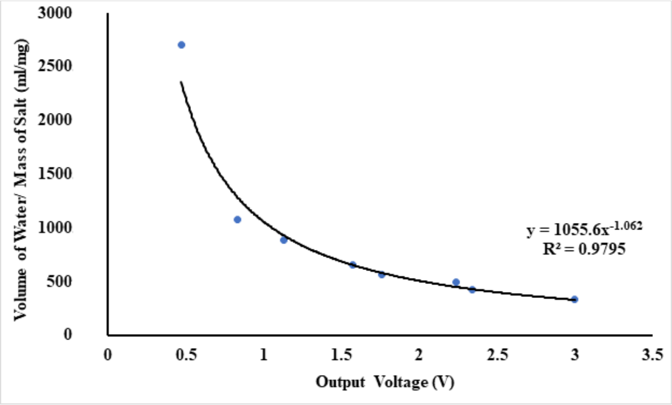

Figure 6: The calibration graph of designed salinity sensor

III. RESULTS AND DISCUSSIONS

This chapter shows the result so far was done and the outputs are as followed. The data analysis obtained from designed salinity sensor, this includes statistical comparison of the readings from the new sensor.

3.1 Data Analysis

Correlation coefficient (R) Figure 6, root-mean-square error (RMSE)(2), mean-bias error (MBE) E (3), and standard deviation (SD) (4) were employed for statistical comparison between the readings of the new sensor and that of the reference material [20].

$$RMSE = \sqrt{\frac{\sum\left(X_{mss,i} - X_{mcs,i}\right)^2}{n}} \qquad (2)$$

$$MBE = \left[n^{-1}\sum_{i=1}^{n}|e_i| = \bar{P} - \bar{O}\right] \qquad (3)$$

$$SD = \sqrt{\frac{\sum(x - \bar{x})^2}{N - 1}} \qquad (4)$$

The results of the MBE, RMSE, STDEV, and R obtained from the comparison of the constructed sensor against the reference were -0.5535, 1.3825, 3.484, and 0.9897, respectively. The R value shows a very good association between the data obtained from the constructed salinity sensor and the reference material (0.9897). Also, we observed that the error margin (MBE, RMSE, and STDEV) between the constructed sensor and the standard was relatively small, confirming an excellent performance of the new sensor.

IV. CONCLUSION

A salinity sensor has been designed, constructed and calibrated. The data obtained from the constructed sensor was compared with a standard sensor at Physics Laboratory, the Federal University of Technology, Akure Nigeria for indoor calibration. The designed salinity measuring sensor gave a calibration coefficient equation 1055.6exp-1.062 ml/mg/volt (Figure 6) with regression co-efficiency of 0.9897, the regression co-efficiency values shown that there is very good associations between the data obtained from the designed sensor. The constructed sensor was found to be viable and capable of field deployment and it can be constructed locally using available sourced materials.

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