

Design of Cost Effective Total Dissolved Solids Logger for Water Quality Monitoring in Mining Communities*

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Abstract

Mining operations adversely affect water bodies by way of releasing toxics into local streams and filling in entire valleys. There are fears that, mining activities could cause serious metal pollution to water resources in its catchment area. This poses a threat to human use as well as the existence of aquatic organisms. The number of victims affected by mining related diseases is bound to escalate in the future if effective monitoring water resource around its catchment area is not conducted. In view of this, there is the need to have a system that would aid environmental authorities to monitor the pollution levels of these water bodies around the mining communities. This paper seeks to design a cost effective logger that could be used to monitor the degree of ionic concentration of these water bodies found around mine operation areas. The device measures and monitors the Total Dissolved Solids (TDS) levels of these water bodies around the mining.

Keywords: Mine Operations, Water Bodies, Total Dissolved Solids, Logger, Water Pollution

1 Introduction

Water quality describes the chemical, physical, and biological characteristics of water, generally in terms of suitability for a particular or designated use (Farrell-Poe, 2000). Demand for water is increasing at an alarming rate and so are people's water quality expectations. High quality, readily available, and safe water, is essential to the quality of life of mankind. Research around mining communities has revealed that surrounding water bodies and even ground water contains traces of heavy metals such as arsenic, lead, cadmium and mercury. Heavy metals in ground waters cause serious health problems in many parts of the world. Surface water is an important component of fresh water systems and its monitoring is essential in attaining a comprehensive understanding of the physical, chemical, and biological characteristics of aquatic systems (Ivan *et al.*, 2011). A study carried out in an area in western region, Ghana, an area that has a long history of mining activity revealed that metal concentrations in groundwater exceed WHO's guidelines (Asklund and Eldvall, 2005) and (Balfors *et al.*, 2007).

Water characteristics, such as dissolved oxygen, pH, nutrients, and temperature, are the physical, chemical or biological parameters monitored. It is very important to sample and monitor all these water conditions and characteristics over time since they are important to human and aquatic health and also has an important use in agricultural and industrial use. (Farrell-Poe, 2000). Total dissolved solids or salinity are a measure of the amount of dissolved ions such as potassium, sodium, chloride, carbonate, sulphate, calcium, and magnesium all

contributing to the dissolved solids in the water (WHO, 2003).

Measuring total dissolved solids is a way to estimate the suitability of water for human drinking and other purposes. This is an important parameter for drinking water because high TDS values may result in a 'salty' taste to the water. (Farrell-Poe, 2000). TDS is measured by measuring the electrical conductivity of the solution. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, carbonate and phosphate (anions) or sodium, magnesium, calcium, iron, and aluminium (cations). Thus, a solution with a high concentration of ions would appear to conduct water effectively because the mobility of these ions enhance conductivity (Farrell-Poe, 2000).

On the other hand, a low conductivity in water reflects the dominance of organic compounds such as oil, alcohol, and sugar. The choice of conductivity measurement depends on the amount of conductivity, corrosiveness of the liquid, and amount of suspended solids. Practically, conductivity is measured by applying a voltage between two electrodes. The drop in voltage between the two electrodes is used to measure the resistance in the water, which is converted into conductivity (Ivan *et al.*, 2009).

In Figs. 1a and 1b, the motion of ions in the electric field carries current through the solution where the cations migrate to the negative electrode, and the anions to the positive electrode and the solution acts as an electrical conductor. Often contacting conductivity sensors are made up of two metal electrodes, usually stainless steel or titanium, in

contact with the electrolyte and an alternating voltage is applied to the electrodes. The electric field causes the ions to move back and forth producing a current and Ohm's law is used to calculate the resistance of the solution.

$$R = \frac{V}{I}, \quad R = \text{resistance}, V = \text{voltage}, I = \text{current}$$

The ionic current depends on total concentration of ions in solution and on length and area of the solution through which the current flows. The current path is the logger geometry, or cell constant, with unit l/cm^2 (length/area). Conductivity which has unit Siemen per cm (S/cm) is achieved by multiplying the conductance by the cell constant for the effect of sensor geometry on the measurement. Conductivity of water may be converted into a measure of the total quantity of ions or dissolved solids (Ivan *et al.*, 2009). Fig. 2 shows the approximate conductivity of some typical electrolyte solutions and conductivity of pure water, distilled water, and typical electrolytes at a temperature reading value of 25°.

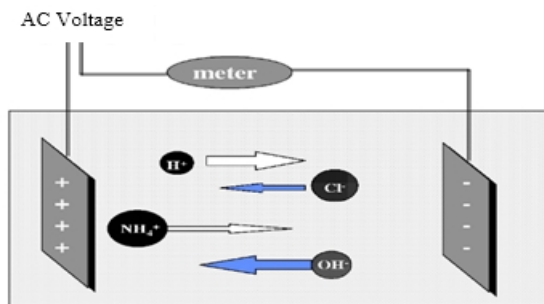


Fig. 1a Schematic of a Simple Conductivity Measurement System

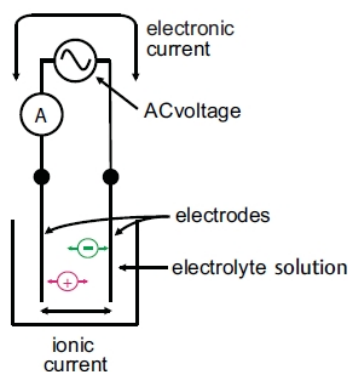


Fig. 1b Basic Conductivity Measurement

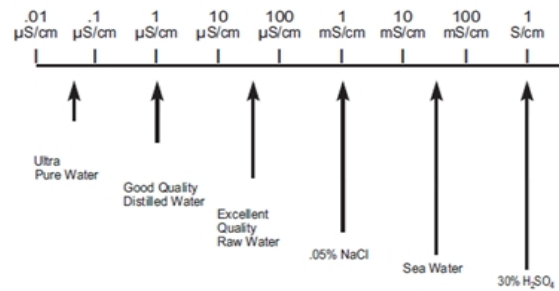


Fig. 2 Conductivities of Different Solutions

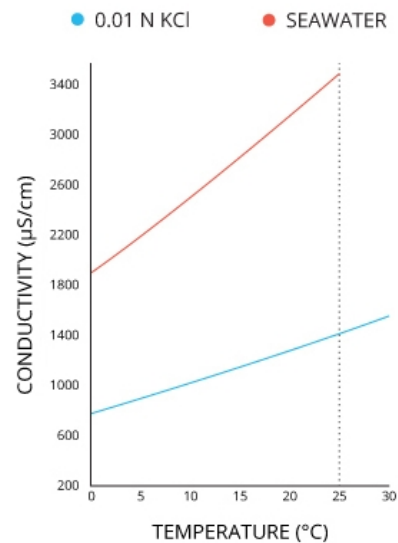


Fig. 3 Dependence of Conductivity on Temperature

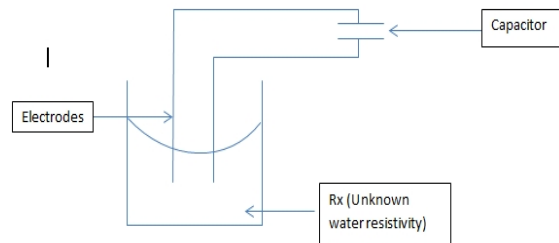


Fig. 4 Basic Concept

When water temperature increases, so will conductivity. For every 1°C increase, conductivity values can increase 2-4%. Temperature affects conductivity by increasing ionic mobility as well as the solubility of many salts and minerals. Due to temperature's direct effect, conductivity is measured at or corrected to a standardized temperature (usually 25°C) for comparability.

Fig. 3 shows that the conductivities of sodium chloride solution and sea water both increase rapidly increase temperature (Golnabi *et al.*, 2009).

2 Resources and Methods Used

2.1 Use System Design

The operation of the embedded system designed here is to measure the conductivity of an unknown solution by measuring its resistivity. Resistivity is the inverse of conductance, hence by measuring the resistivity of an unknown solution it can be equated indirectly to obtain the conductivity.

$$R_x \propto \frac{1}{\sigma}, R_x \text{ is measured resistivity of the solution}$$

The measurement of conductivity of liquids may be done in several ways, provided neither continuous level of voltage nor impulse voltage is applied.

The method adopted here uses an electrical field that oscillates very rapidly instead of using direct current (DC). Using this method limits the overall movement of ions toward the electrodes. With this, the ions move one way for fraction of a second, and back the other direction for the second half of the cycle. Effectively the solution and electrodes sojourn unchanged and the conductivity is accurately measured. Pure water shows intrinsically a much reduced electrical conductivity (0.00548 mS/m). With adulterated water, ions separate and conductivity increase. Upon application of a voltage between two or more electrodes made of non-reactive materials, positively charged ions such as:

$Na^+, Ca^{2+}, Mg^{2+}, H^+$ etc and negatively charged ions such as Cl^-, SO_4^-, HCO_3^- etc will constitute an electrical current. The conductivity of water may then be converted into a measure of total quantity of ions or dissolved solids (Ivan *et al.*, 2009). Fig. 5 shows the parts of the TDC device.

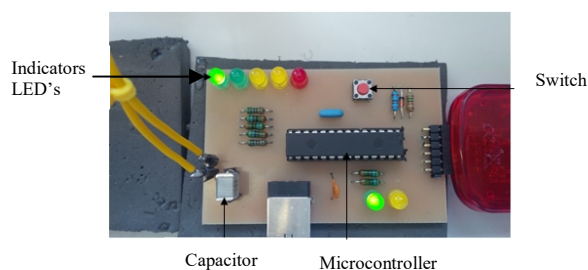


Fig. 5 TDS logger

The TDC logger is made up of a $0.33\mu F$ capacitor which acts as a rapid oscillating electric field for storing charges that would be discharged through the subject solution. In this application the

condenser acts as alternate current (AC) which can store electricity temporary and discharges. It must be noted that the capacitor used decays exponentially hence a very small capacitance would be ideal for the sensor. In exponential decay equation (1) below, it is seen that, time for discharge is directly proportional to the product of unknown resistance R_x and the capacitance.

$$Q = Q_0 e^{\frac{-t}{RC}}$$

$$\Rightarrow \ln \frac{Q}{Q_0} = \frac{-t}{RC}$$

$$\Rightarrow t = \left[-\ln \frac{Q}{Q_0} \right] \cdot RC$$

$$\Rightarrow t = K \cdot RC$$

$$\therefore t \propto RC \dots\dots\dots(1)$$

Q = Charge at time t
 Q_0 = Initial Charge
 t = Time decay
 R = (R_x) Resistance
 C = Capacitance

The PIC microcontroller used for the logger has an on-chip program memory for the firmware, or coded instructions to run a program. A Program Counter is used to address program memory, including Reset and interrupt addresses. A hardware stack is used with call and return instructions in code but not part of the program memory. Device data sheets describe the details of program memory operation, vectors and the stack. The microcontroller has data or file register memory which consists of Special Function Registers (*SFRs*); used by Central Processing Unit (*CPU*) and peripheral functions for controlling the desired operation of the device and General Purpose Registers (*GPRs*) for storage of variables needed by program for computation or temporary storage.

18f2525 PIC microcontroller was used for the sensor due to its fast setting pins and states connecting test probes and enabling threshold voltage detection using its Complementary Metal Oxide Semiconductor (*CMOS*) trigger and period of time for an event obtained by 16-bit counters of timer 1. These indicators positioned at the upper left reflect the output of the timer values. The output values are interpreted in parts per million (ppm) represented by using LED. The switch enables commencement of charge and discharge cycle (Kumar *et al.*, 2010). Table 1 gives the cost analysis for the TDS logger.

Table 1 Cost Analysis of TDS Logger

Component	Quantity	Unit Cost (GH¢)
PIC 18F2620	1	24
Plastic capacitor	1	4
Push button switch	1	4
Indicator LED's	1 Pack	9
Wire connectors	1 Pack	10

2.2 System Development

MPLAB X Integrated Development Environment (IDE) version 2.3 .1 was the software used to write, edit, debug and program the codes for the Microchip microcontrollers and digital signal controllers. An embedded system is a design that uses microcontroller combined with a microprocessor unit (CPU) with additional circuits called peripherals. This single device can then be embedded into other electronic and mechanical devices for low-cost digital control (Kumar *et al.*, 2010).

MPLAB X IDE contains all the components needed to design and deploy embedded systems applications. The procedures for developing an embedded controller application are:

2.2.1 Algorithm of the Logger

The algorithm for the logger steps through the following:

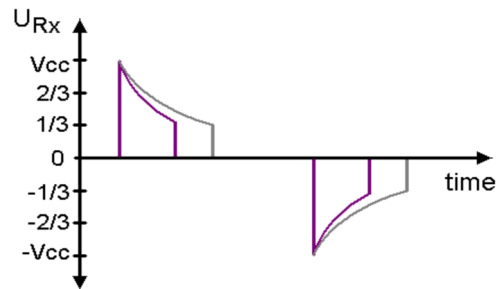
- Charge the capacitor close to V_{dd} ; the supply voltage
- Begin discharging the capacitor
- Time for discharging capacitor is recorded as T1
- Ground the capacitor
- Charge the capacitor to the opposite polarity as in step 2; thus $-V_{dd}$
- Begin discharging the capacitor
- Time for discharging capacitor is recorded as T2
- Compare discharge times
- Light LED

Fig. 8 shows the flow chart for the logger algorithm.

2.3 System Testing

A total of 16 cycles were performed and corresponding T1 and T2 time values were averaged and converted by means of look-up tables stored in Electronically Erasable Programmable

Read Only Memory (EEPROM). In this case it is conversely proportional to R_x value. Two voltage waveforms across R_x (electrodes) are presented for different water resistivity. Solution with longer discharge time implies higher conductivity and vice-versa. The curve in magenta represents higher water conductivity value than that of the grey. TDS of the subject solution was recorded before calibration by taking readings from a TDS hatch meter.

**Fig. 7 A Graph Comparing Discharge Events**

3 Results and Discussion

3.1 Experimental Results

The experiment was conducted at a solution temperature of 21.2 degrees Celsius.

640ppm = 1mS/cm

302ppm = 0.47 mS/cm

4430ppm = 6.9 mS/cm

8270ppm = 12.9 mS/cm

The following precautions were noted;

- The test probe electrodes had similar geometry and spaced at relatively small distance of about 3.5mm. Varying the distance results in change of cell constant K . The cell constant K of an electrode is the ratio of distance of separation to area of the electrodes.

$$K = \frac{d}{A + AR}$$

d : Distance of separation

A : Area of electrodes

AR : Fringe electric effect.

A change in K affects the conductivity in the following equation:

$$\sigma = KG$$

K : Cell constant

G : Conductance

$$G = \frac{1}{v}$$

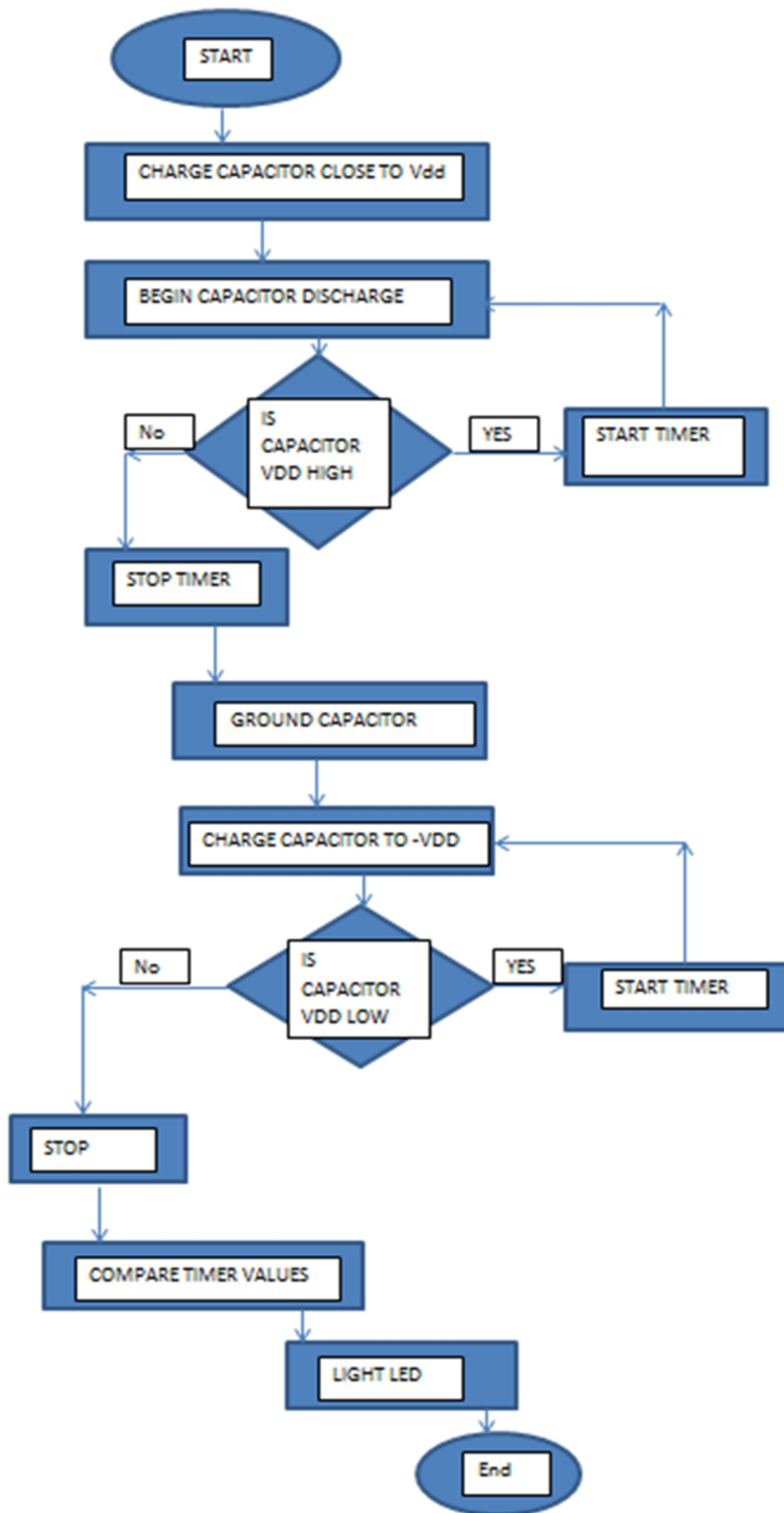


Fig. 8 Flow Chart of the Embedded System

The aim here is to achieve cell constant close to 1 and therefore, the probes should be close as much as possible.

- The probes are cleaned and wiped each time the subject solution is changed.

3.2 Graphical Analysis

Figs. 9, 10, and 11 show discharge times of solutions with TDS of 0.47mS/cm, 6.9mS/cm and 12.9mS/cm respectively for 16 events and table 2

shows the average discharge times for same. On average from table 2, higher discharge time is recorded for solutions with lower TDS because it offers higher resistance. From the result obtained from the three solutions, it suffices to say that conductivity increases with rise in ionic concentration of a solution. This inference is based on the averaged positive and negative discharge cycle values obtained for the experiment.

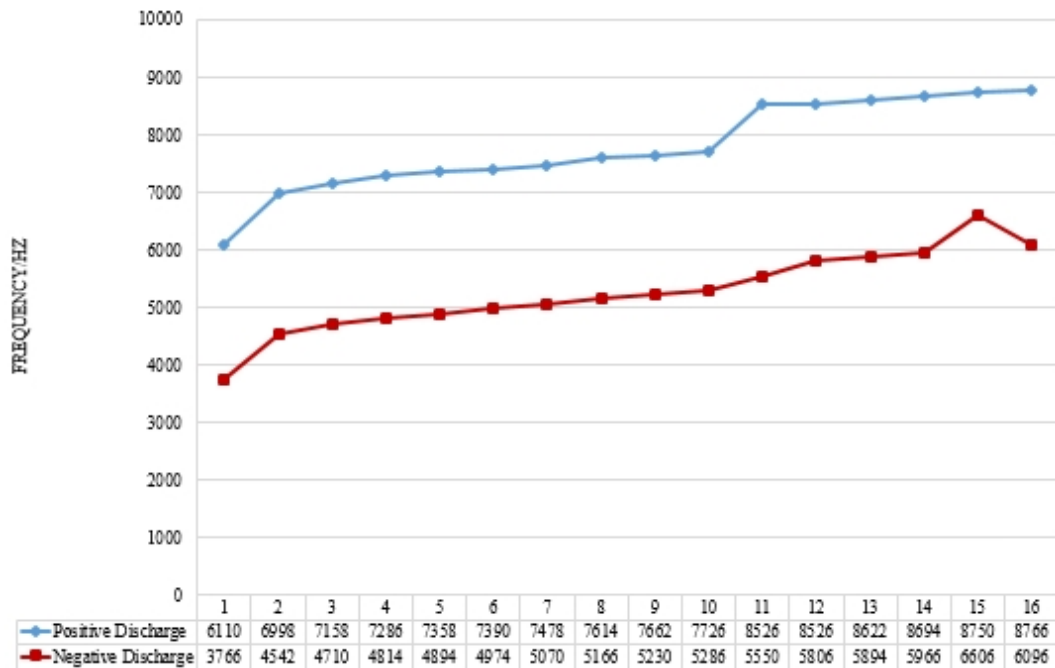


Fig. 9 Discharge Time for Water at 0.47mS/cm

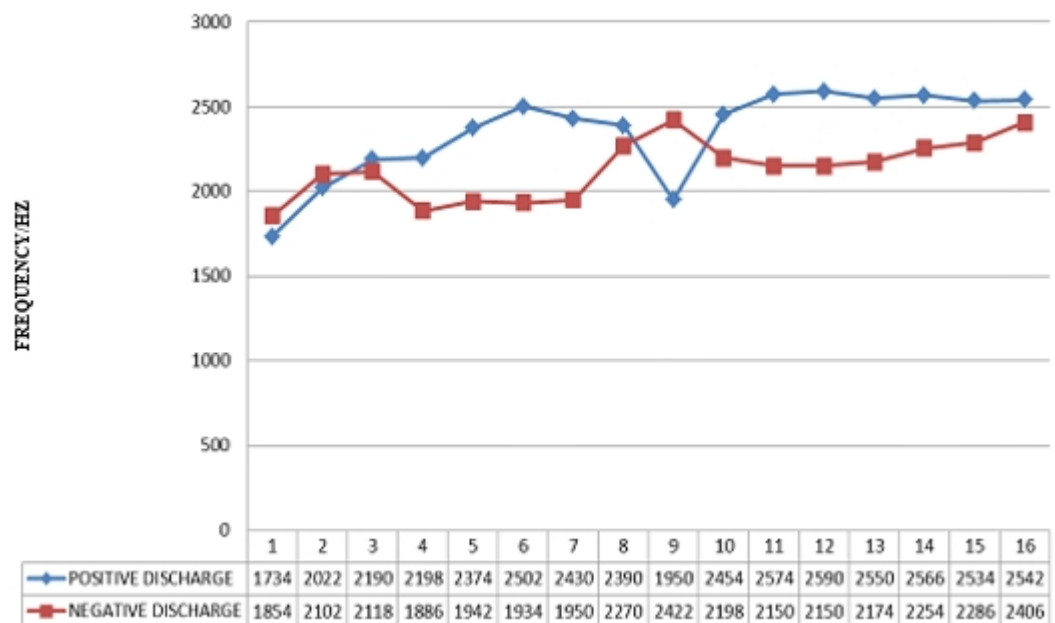


Fig. 10 Discharge time for brine at 6.9mS/cm

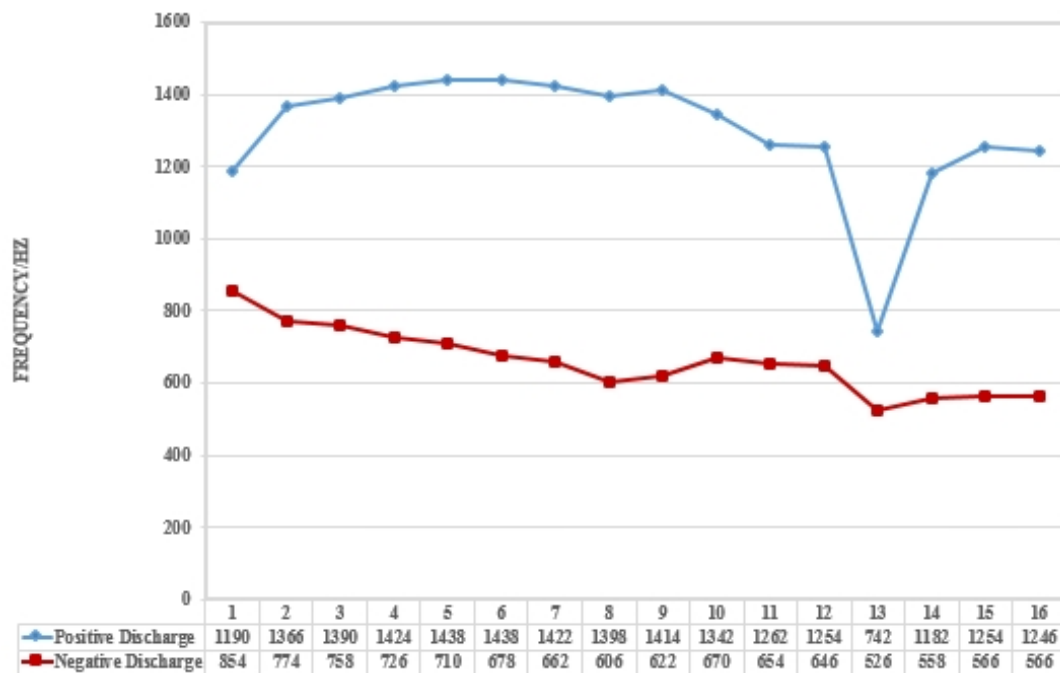


Fig. 11 Discharge time for water at 12.9mS/cm

Table 2 Average Discharge Times for the Solutions

Discharge	0.47mS/cm	6.9mS/cm	12.9mS/cm
Positive Discharge	77915	2350	1298
Negative Discharge	5236	2131	661

3.3 Positive versus Negative Discharge

It was generally observed that the positive cycles take longer durations to discharge compared to negative cycles as seen in Figs. 12 and 13. The

cations are drawn to C_+ electrode during the negative discharge. This implies cations are better conductors than anions.

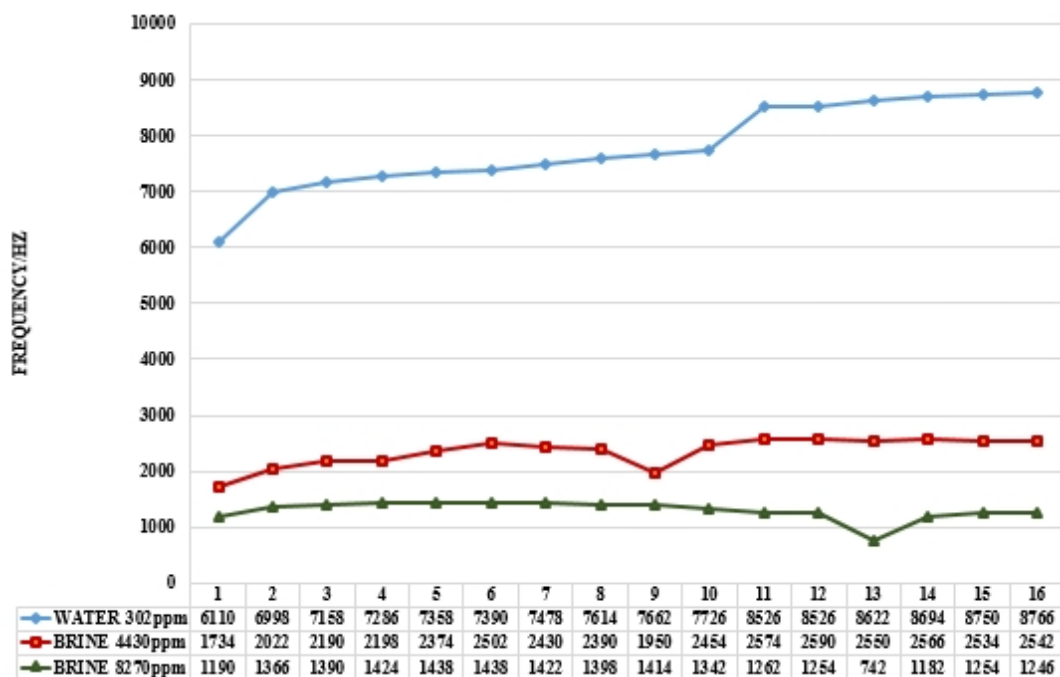


Fig. 12 Positive Cycles Discharge Time

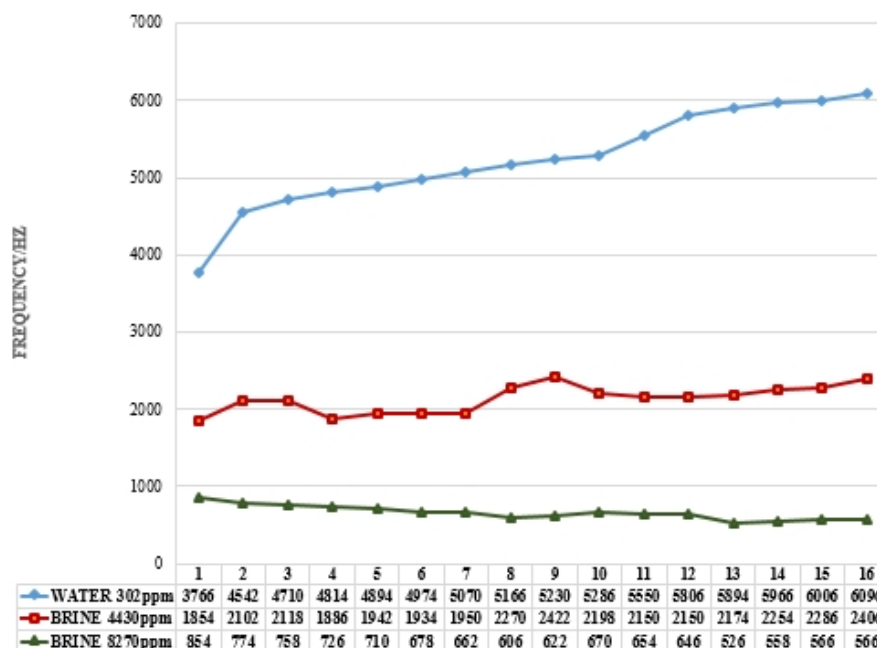


Fig. 13 Negative Cycles Discharge Time

4 Conclusions

The cost-effective TDS logger embedded system intended for water quality monitoring activities was designed with its necessary functionalities. This TDS logger is intended for large scale monitoring such as along rivers or in urban water systems. It is based on an 8-bit PIC microcontroller architecture and a small EEPROM memory. The low cost logger can be used for continuous monitoring and provides a quick test of the water quality, preventing unwanted health problems.

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