Low Cost pH Meter Using pH Acid-Base Indicator Method And Spectrophotometry Concepts

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***Abstract*— A low-cost pH meter was developed using the acid-base indicator and spectrophotometric concepts. The acid-base indicator Phenol Red was added to aqueous solutions of acetic acid, at pH ranging between 6.0 and 8.2 and sodium bicarbonate was gradually added. Red and green LED lights were emitted through the test tube containing the analyzed solution with acid-base indicator, and the brightness on the other side of the tube was acquired in two LDR photo-sensors, similar to a spectrophotometric process. Then the electric resistance values of the LDRs were tabulated and a multiple linear regression analysis was performed between these values and the pH value acquired by a commercial pH meter. One can then apply electrical resistance values of the LDRs in future experiments to the equation generated by the multiple linear regression, estimating the pH of a desired solution. This study has the advantage of the low cost and simplicity of acid-base indicators methods combined with the readability of digital measurement of electrometric methods.**

***Keywords*— pH, low cost pH measurement, spectrophotometric measurement of pH, spectrophotometry.**

I. Introduction

The concept of pH (hydrogen potential) is studied since the mid-nineteenth century up to the present times and is intended to quantify the values of acidity and alkalinity of a solution [1]. The pH is a measure of concentration of hydrogen ions [2] in an aqueous solution and used to indicate their degree of acidity, neutrality or alkalinity [2]

The pH measurement can be accomplished by two methods: the electrometric form or by acid-base indicators. The electrometric measurement works by measuring the hydrogen ions concentration through a glass bulb connected to an electronic instrumentation [3], measuring a continuous pH scale. However, pH measurement using acid-base indicators is based on the use of substances that change color according to pH [4]. Add a few drops of this indicator in the solution to be analyzed and the color of the solution can be compared with a discrete color scale, that can indicate discrete pH values. The electrometric measurement has the advantage of showing the pH value in a digital display in the pH meter, while the measurement with indicators is performed from a visual comparison of the solution color with the predefined discrete color scale [4].

Similar to spectrophotometry equipments that use light to infer chemical characteristics of a solution, the propose of this study is to develop a pH meter that analyzes the color of a solution in the presence of acid-base indicator, with the pH measured on a digital LCD display. This proposal provides the low cost and simplicity of acid-base pH indicator methods combined with the readability in a display of a continuous pH scale, as in electrometric methods.

II. OBJECTIVES

This study has the objective to develop a pH meter through the acid-base indicator method measuring light intensity variations in the LED light transmitted through the solution, just like in spectrophotometry systems. The proposed system aims to measure continuous ranges of pH, with and easy digital display pH reading and the low cost and simplicity of the acid-base indicator method.

III. pH MEASUREMENT USING SPECTROPHOTOMETRY CONCEPTS

The pH is a measure of hydrogen ion concentration [H +] in solution and used to indicate the degree of acidity, neutrality or alkalinity of a solution. In terms of classification: solutions with pH 0 to 7 are called acidic solutions; solutions of pH 7 are neutral solutions, and pH 7 to 14 are called alkaline or basic solutions [5].

A. *pH Measurement using acid-base indicator*

The pH measurement by acid-base indicator is based on the use of substances that change color according to pH [4]. This color is compared to a discrete scale of colors as shown in Fig. 1. The pH of a solution can be measured adding the acid-base indicator to the solution and visually comparing the final solution color to this scale.

The measurement of acid-base indicator has the advantage of being a simple low cost method, with the disadvantage of only allowing the measurement of the discrete pH values present in the scale [3].

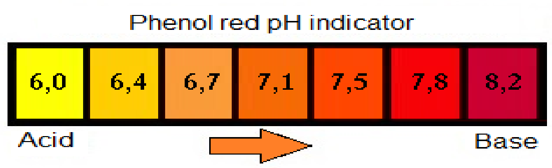

Fig. 1 – Phenol Red acid-base indicator scale in which a solution containing this indicator is visually compared to check the pH of the misture. Red colors indicate alcaline solutions while acid ones are indicated by yellow colors.

Furthermore, the visual comparison necessary for checking the pH may generate errors and no transparent solutions may interfer to the final color after mixing the indicator, showing wrong pH measurements when a visual comparison is performed with the scale in the Fig. 1. Another way to measure pH then, is the electrometric measuring, as presented below.

B. Electrometric pH measurement

The electrometric pH determination method is performed through a device called pH meter. This device works by measuring the electric voltage generated in a glass bulb sensor, selective to Hydrogen ions concentration [3]. The voltage supplied by the equipment is a function of the pH of the solution [3]. The electrometric measurement has the advantage of measuring a continuous range of pH and show them on an LCD display.

The electrometric equipment require battery replacement and calibration and sometimes maintenance but has the advantage of not contaminating the solution with acid-base indicator chemicals, such as in the acid-base indicator method that requires that the analyzed sample is discarded [6].

C. Spectrophotometry

The spectrophotometer is widely used chemical and clinical analysis laboratories. Throughout the spectrophotometry, unknown substances that form an analyzed solution can be identified by their characteristic light spectra in the range of ultraviolet, visible or infrared light [7].

A spectrophotometer is basically a device that measures the absorption of light passing through a solution. The light emitted by a lamp passes through a transparent vessel containing the solution to be analyzed. On the other side of the vessel, a light sensor measures the light intensity and the calculation of the difference between the light emitted by the lamp and received in the sensor is performed. This variation in intensity is verified for different frequencies of light, leading to the solution absorption spectrum [8]. This spectrum can be compared with tabulated spectra and substances that form the solution can be identified by spectrophotometer [8].

The concept of using different frequencies of visible light (different colors) that pass through solutions is the principle of spectrophotometry and will be used here for measuring pH, as will be shown below.

D. Using lights to indicate pH of a solution

The concept of acid-base indicator of the subsection 3.1, shows that by adding an acid-base indicator to a solution, the color of the misture can be visually compared to a color scale (Fig. 1) indicating the pH. However, using the concept of spectrophotometry, one can shine a light in a solution containing acid-base indicator and the brightness can be function of the pH.

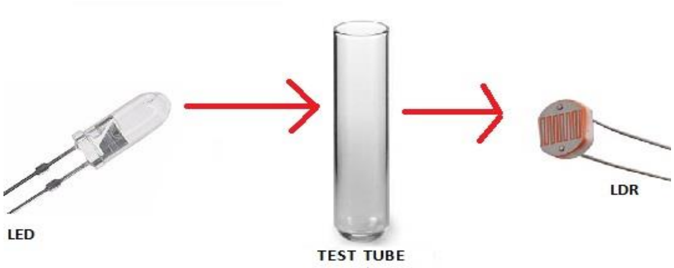

Figure 2 - Simplified representation of a spectrophotometry. The test tube receives light of a lamp and a photo sensor captures the light from the other side. The light absorption generates a light intensity difference between the inlet and the outlet, indicating the spectrum of the solution and thus its chemical composition.

Spectrophotometers are very expensive devices, costing thousands of dollars. The concept however, is quite simple and can be explored somehow economically [11]. A spectrophotometer using inexpensive and easy-to-find materials can be created by applying light on a test tube with a solution inside [11]. The light passing through the test tube is measured by a light detector and its brightness difference between the emitted and received light can identify that the substance to be examined [11].

Using the same principle, the pH of a solution can be measured by adding a few drops of Phenol Red (1 drop per every 36 drops of solution). Phenol Red is an acid-base indicator with reddish color in the presence of alkaline solutions (pH> 7) and yellow in the presence of acidic (pH <7) solutions, working in the pH range of 6.0 and 8.2 [9]. This indicator is used here for its commercial availability and low cost, easily found in swimming pool supply and aquarium companies.

The white light spectrum is composed of three primary colors that mixed, can generate all other colors in the visible light spectrum: the red light, green light and blue light [10]. Fig. 3 shows that the red color is formed only by the red light since it is a primary color. The yellow color however, is formed by the union of the red and green colors, for instance.

A red color object, is nothing more than an object that allows the transmissions of red light, absorbing all other lights of other colors [12]. For example, if a red cellophane sheet covers a source of blue light, the blue light is absorbed by the cellophane and the light source will appear to be turned off from the other side of the cellophane. However, if a blue or violet cellophane (because violet is composed of the blue and red colors, as shown in Fig. 3) is placed over the same source of blue light, then the light source will be able to transmit its light through the cellophane, and its light may be noticed through the paper.

So once the Phenol Red changes its color between red and yellow (since yellow is formed by the red and green color), a red and a green LEDs were employed in the present study. Similarly as the cellophane sheet absorbs frequencies of light, also Phenol Red absorb some amount of red or green light, so that the light variation can be used to identify the solution pH.

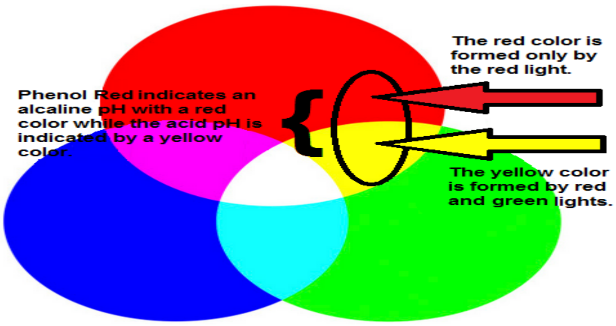

Fig. 3 - The acid-base indicator Phenol Red has a yellow color in the presence of acids, and a red color in the presence of alkaline solutions. So the luminance variations in the color red (red light) and yellow (red and green) can be used to infer the pH of a solution with this indicator.

IV. PROTOTYPE ASSEMBLY AND EXPERIMENT

The following components were used to assemble the pH meter proposed: a green and a red bright LEDs as the source of light. These LED colors were chosen because the Phenol Red acid-base indicator varies its colors from yellow (formed by the red and green color) to red (formed only by the red color).

The light from LEDs passes through a glass test tube containing 144 drops the solution whose pH is been analyzed, together with 4 drops of Phenol Red (Neptune ®). Two LDR (Light Dependent Resistor) type light sensors measure the level of light passing through the test tube. The device is powered by a 9V battery connected to a 5V voltage regulator to keep the voltage (and intensity) of the LED constant, independently of the battery charge, as shown in Fig. 4. The LEDs are connected to two resistors of 220 Ω to limit the electric current of each of the LEDs, and the LEDs can alternately be turned on by a switch.

The prototype body was constructed from a plastic box of 15 x 5 x 8 cm, with a perforated lid to introduce the test tube, painted with black ink to prevent light interference caused by both external environment and internal reflections on the walls of the box.

The two LDR terminals are connected to external digital multimeters, in order to inform the electrical resistance values of LDR perpendicular and lateral to each of the LEDs, as in Fig. 4.

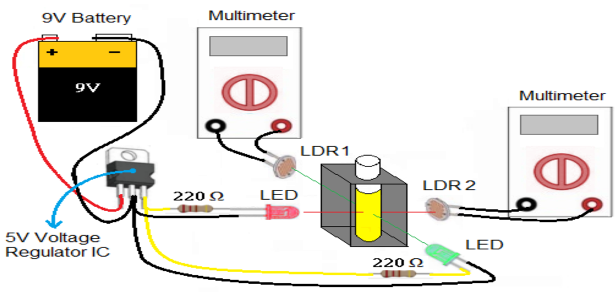

Fig. 4 - The light from LEDs pass through a test tube containing a solution with acid-base indicator and is measured in two LDRs so that a relationship between pH and brightness can be calculated.

V. PROTOTYPE CALIBRATION AND EXPERIMENTATION

During the experiment, 33 test tubes were prepared, each containing a solution of Acetic Acid (99%, Sigma Aldrich ®) and Sodium Bicarbonate (Powder, Farmax ®), with concentrations varied to adjust the pH of the solutions linearly between 6.0 and 8.27 linearly, varying from about 0.05 pH units from each tube. The pH was adjusted in each test tube using a digital electrometric pH meter (ATC ®, Model PH-009).

In addition, 4 drops of Phenol Red indicator with 144 drops of the analyzed solution were added to each test tube (this concentration was indicated by the acid-base indicator manufacturer).

Then the test tubes were inserted into the prototype and the red and green LED lights are alternately turned on. The electrical resistance of both LDRs are measured with multimeters, so that the pH could be correlated mathematically with the LDRs electrical resistance values from a multiple linear regression. This equation was generated by the multiple linear regression module of Excel 2016, and allows other pH values to be inferred simply by inserting in the equation the electric resistance values of both LDRs as performed in calibration step.

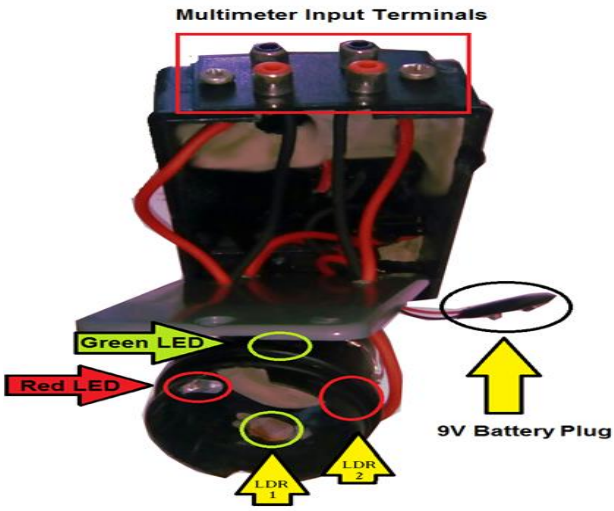

Fig. 5 - Exploded view of the proposed pH measurement equipment. Each LED has an LDR on the opposite side of the test tube.

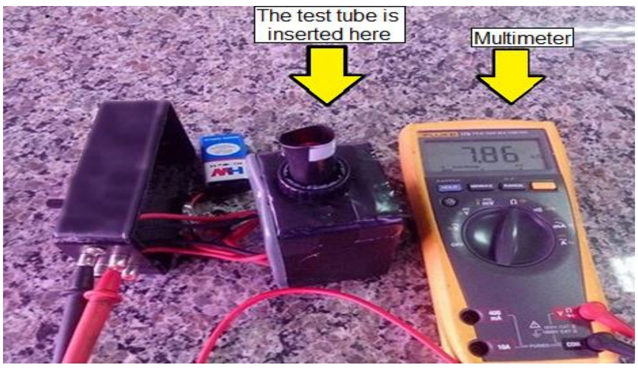

Figure 6 – Prototype photograph. A test tub is placed inside the equipment, the battery is connected and the box is closed shielding it to outdoor lighting. Then a multimeter is connected to the external terminals of the two LDRs and the LEDs are alternately switched by a key to performed the LDRs electrical resistance measurements.

VI. RESULTS

The LDR electrical resistance measurements of the 33 test tubes on both LDRs, illuminated with the red and green LED lights are plotted in the graph of Fig. 7. The horizontal axis represents the pH values measured with the commercial electrometric pH meter, and the vertical axis is the electrical resistance of the LDRs.

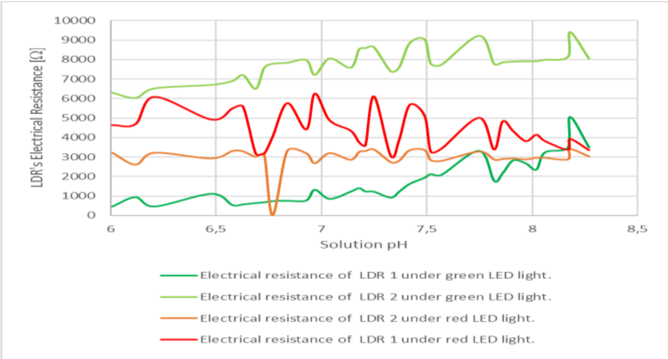

Figure 7 - Electrical resistance measurements of the 33 test tubes in both LDRs, illuminated with red and green LED light.

The equation of the Fig. 8 is the multiple linear regression relating the measured pH as a function of the electrical resistance measurements of the LDRs.

$$pH = 5{,}3568 + a.3{,}4600.10^{-04} + b.2{,}4416.10^{-04} - c.9{,}4184.10^{-06} - d.1{,}2513.10^{-04}$$

a – Electrical resistance of LDR 1 under green LED light.
b – Electrical resistance of LDR 2 under green LED light.
c – Electrical resistance of LDR 2 under red LED light.
d – Electrical resistance of LDR 1 under red LED light.

Figure 8 – Equation of the multiple linear regression and his subtitle.

VII. DISCUSSION

The experimental measurements of the electrical resistance of the LDRs (Fig. 7) are consistent to what was expected. Due to Phenol Red, acid solutions (pH close to 6) had a yellow color; as Sodium Bicarbonate was added, the pH of the solution increased and the solution color turned red. In terms of luminance, a yellow solution (formed by the red and green color) is transparent to green light, causing a decrease in electrical resistance in the LDRs (as the electrical resistance of LDRs is inversely proportional to the light intensity). Alkaline solutions are reddish, blocking the green LED light, reducing the light intensity transmitted to the LDRs, consequently increasing LDRs electrical resistance, as shown in Fig. 7.

From the acquired data, an equation could be generated by the multiple linear regression, relating the pH values as a function of the electrical resistance of the LDR 1 and LDR 2, under the light of the green LED; and the electrical resistance of the LDR 1 and LDR 2 under the light of the red LED. The multiple regression equation provided a Pearson correlation coefficient close to unity (R = 0.9055). This means that the equation suggested a strong linear tendency. However, further studies with more solution samples could perhaps increase the correlation coefficient, showing with more centanty if the data is actually linear, or there is better mathematical model to be used in the fitting.

In addition, if only the LDRs perpendicular to the LEDs (green LED with LDR 1 and red LED with LDR 2) were used, multiple regression would lead to a smaller correlation coefficient (R = 0.871705), indicating that non perpendicular LDRs also contribute to increase statistical linearity. The whole experiment and prototyping costed less than USD $30.00, a relatively low cost equipment for a device using spectroscopic concepts. One point to be considered however, is that the solutions to be analyzed require to be transparent (no color solutions allowed), in order to not interfere with the color patterns of acid-base indicators and therefore, the measured pH values.

The present study could demonstrate that the pH measurement with a low-cost machine using spectrophotometry concepts is possible and that the results show that the electrical resistance of LDRs is influenced by the color variation of the Phenol Red indicator and consequently, the pH of the solution.

VIII. CONCLUSIONS

The methodology proposed in this paper could provide improvements in the pH measurement method using acid-base indicator. An inexpensive pH meter could be developed using spectrophotometry concepts, bringing the advantages of the electrometric continuous pH range measurements and readability in LCD displays, opening doors to new studies in pH meter and biochemical instrumentation field.

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