CONSTRUCTION AND PERFORMANCE TESTS OF A pH METER FOR PHYSICO-CHEMICAL CHARACTERIZATION

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Abstract
This paper reportedly demonstrated the successful construction of a pH-meter which uses microcontroller based in measuring solutions of water and different samples. It is a versatile system, and by simply replacing the sensors and making some changes within the computer code, the system can be used to measure the acidity and alkalinity of different solution samples. The standard deviation and the correlation coefficient of these results show high linearity of the constructed device. Buffers 4, 7, 9 and 10 were used to calibrate both pH meters. The results were reproducible being displayed on a LCD. Paired sample correlation reveals that the relationship between the fabricated and imported pH meters was significantly relevant (P=0.000<0.05), has a very strong relationship and a positive correlation of 0.992. This implies that the fabricated and imported pH meters have very close performance.

1. Introduction

The determination of pH is one of the most common processes in chemical measurements today. The pH meter is an essential piece of equipment in most laboratories, vital for many analytical and synthetic processes[1]. In addition to measuring the pH of liquids, specially designed electrodes are available to measure the pH of semi-solid substances, such as foods. These have tips suitable for piercing semi-solids; they have electrode materials compatible with ingredients in food, and are resistant to clogging [2]. Typical applications include medical usage like blood pH, ulcer and gastric tests in clinics, petrochemical industry, food and agriculture, purification of drinking water, pharmaceuticals and cosmetics industries, effluent treatment plants, dyes and chemicals plants, biotechnology laboratory, electroplating centers, circuit board etching laboratories, flue gas scrubbers, paper manufacturing industries and fermentation (wine, beer, alcohol) centers. The common assertion that neutral solutions have pH 7 is not true. The statement is true only if the temperature is 25°C [4]. pH measurement in the laboratory is done by measuring the cell potential of that sample in reference to a standard hydrogen electrode[5]. pH lower than 0 or higher than 14 may exist, when the concentration of H⁺ takes some extreme values [6]. Air always contains small amounts of carbon dioxide which dissolves in water making it slightly acidic with pH of about...
A pH meter is nothing else, but precise voltmeter, that measures EMF of the pH electrode [8]. The reliability and precision of today’s pH meter are much better, although they are still limited by the electrode construction and properties of the solution itself. This however motivated the current study to construct a cheap pH meter for experimental demonstrations in colleges and schools most especially secondary schools in order to be used for physico-chemical analysis.

2. Experimental details

2.1 Principle of Operation of the pH Meter Circuit.
When the button at PIN 15 of a microcontroller is pressed, this sets the transistor BC548 at LOGIC 1 (ON STATE), at this stage, the pH-sensor is discharging, which makes the output to the comparator LM 393 go to LOGIC 0, this is fed to the AND gate. Connected to PIN17 of the microcontroller was the timing circuit output which was the TIME CONSTANT fed to the AND GATE with the LOGIC 0 output from the comparator to give the capacitance value. But if the button at PIN 15 of the microcontroller is released or open, this sets the transistor BC548 at LOGIC 0 (OFF STATE), at this stage, the pH-sensor is charging. The comparator LM 393 keeps charging till it gets to the set voltage 3V, this sets it to go to LOGIC 1 which is fed to the AND gate. Connected to PIN17 of the microcontroller is the timing circuit output which is the TIME CONSTANT fed to the AND GATE with the LOGIC 1 output from the comparator to give the capacitance value.

2.2 Stages of Construction of pH Meter
The construction of the device was implemented in four stages viz; Printed circuit board designing, Soldering on the printed circuit board, Firmware designing and Packaging.

2.3 Printed Circuit Board (PCB) Designing
Proteus8 software was used for the pre-designing and simulation of the circuit diagram before using “EXPRESS PCB” design tool to design the circuit layout. For this construction, the “EXPRESS PCB” design tool is the software that was used to design the circuit layout. The design was then transferred to a copper board through a process called screen printing and then chemically etched. Chemical etching was done by immersing the designed board in ferric chloride solution. The etchant removed copper on all surfaces exposed by the resist. The board was then cleaned in a solvent called “thinner”, dried and the board was ready to be soldered on.

2.4 Soldering on the Printed Circuit Board
In order to ensure good contacts and to avoid dry joints during soldering, all the components to be soldered were first cleaned by scraping their legs with sandpaper until the copper became visible. The copper tracks on the board were cleaned in a similar manner; this made soldering much easier as molten solder flowed freely over such surfaces. Heat was applied at the right temperature and for sufficient time to ensure that a good joint was made. After soldering the circuit components, electrical contact was tested by setting a multimeter to continuity test mode. One terminal of the meter was placed on the soldered joint while the other leg was placed on the copper track to which it was soldered. If the joint was well made, the multi-meter emitted a beep sound and if not, it indicated an open connection.

2.5 Firmware Designing
Firmware is held in non-volatile memory devices such as ROM, EPROM, or flash memory [9]. For this construction, the flow chart for the firmware was first developed based on the working principle of the pH meter. This firmware design involves the software component which includes the programming language used for the device; the assembly language used was ATMEGA8.

2.6 Packaging
The soldered components, the 3D- plastic mounted pH sensor and LCD are mounted on plywood to hold them in place before the final closing (Figure 1).

2.7 Standard Operation Procedure of pH Meter
i. The equipment was powered on from the mains 220V A.C. supply
ii. The ON/ OFF switch was switched ON which showed on the LCD as readings are taken

iii. The solution whose parameter is to be taken is rightly positioned under the pH-sensor such that its level covers the tip of the electrode, and the result is displayed on the LCD.

Table 1: pH Meter Specifications

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Combined Plastic Electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH Range</td>
<td>0-14 pH unit</td>
</tr>
<tr>
<td>Display</td>
<td>Liquid Crystal Display (LCD)</td>
</tr>
<tr>
<td>Power Supply</td>
<td>220Volt 50Hz</td>
</tr>
</tbody>
</table>

Figure 1: Schematic diagram of the fabricated pH meter showing the soldered components, the 3D-plastic mounted pH sensor and LCD mounted on plywood before the final closing.

3. Results and discussion

The fabricated pH meter was tested with standard buffers and different solutions. The same standards were measured using imported pH meter (Jenway product) and the results were compared. Corrections and final adjustments were made by calibrating the fabricated pH meter with standard buffer solutions. Table 1 shows results of the measurements from the fabricated and imported pH meter. The results obtained for the fabricated and the imported equipment were very close despite the fact that Buffers 4, 7, 9 and 10 were used to calibrate the two pH meters. These set of buffers along with other samples were measured and their results were comparable and consistent. Figures 2 and 3 show the graphs of fabricated and imported pH meters against the standard buffers. pH values of both devices I(fabricated and imported) show that the results have a standard deviation of 2.4916 and 2.5200 respectively, and a correlation coefficient of 0.9991 and 0.9983 respectively. These were very close values showing that the fabricated equipment is a good equivalence of the imported pH meter. Also, Figure4 shows the graph of imported pH meter (Jenway) against the fabricated pH meter and follows almost the same pattern. This is also an indication that the fabricated and imported pH meters have almost the same performance and
whatever difference could be taken as systematic errors which may not affect the accuracies of measurements. The results obtained from the imported and the fabricated equipment as depicted in Table 2 showed very close even though their decimal numbers differ but consistent. Buffers 4, 7, 9 and 10 were used to calibrate both pH meters. Tables 3 and 4 on the descriptive statistics show significant relationship between the fabricated and imported equipment. The paired sample correlation reveals that the relationship between the fabricated and imported pH meters was significantly relevant (P=0.000<0.05) and the relationship is very strong as the correlation is 0.992 and positive. This implies that the fabricated and imported pH meters have very close performance.

**Figure 2**: Graph of Fabricated pH Meter Readings against Standard Buffer pH

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>2.4916</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>0.9991</td>
</tr>
</tbody>
</table>
Figure 3: Graph of Imported pH Meter Readings against Standard Buffer PH

- Standard Deviation = 2.5200
- Correlation Coefficient = 0.9983
**Figure 4:** Graph of Imported pH Meter (Jenway) against Fabricated pH Meter

<table>
<thead>
<tr>
<th>SAMPLES</th>
<th>FABRICATED pH METER (x)</th>
<th>IMPORTED pH METER (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STD BUFFER 4</td>
<td>4.61</td>
<td>4.443</td>
</tr>
<tr>
<td>STD BUFFER 7</td>
<td>7.87</td>
<td>7.622</td>
</tr>
<tr>
<td>STD BUFFER 9</td>
<td>9.74</td>
<td>9.418</td>
</tr>
<tr>
<td>STD BUFFER 10</td>
<td>10.66</td>
<td>10.829</td>
</tr>
<tr>
<td>DISTILLED WATER</td>
<td>7.21</td>
<td>7.533</td>
</tr>
</tbody>
</table>
Table 3: Descriptive Statistics for the Imported and Constructed pH Meters

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>X</td>
<td>7.6629</td>
<td>7</td>
<td>2.01108</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>7.60943</td>
<td>7</td>
<td>2.054537</td>
</tr>
</tbody>
</table>

Table 4: Paired Samples Correlations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>x &amp; y</td>
<td>7</td>
<td>0.992</td>
</tr>
</tbody>
</table>

Conclusion

The study reportedly demonstrated the successful construction of a pH-meter measurement which uses microcontroller based in measuring solutions of water and different samples. It is a versatile system, and by simply replacing the sensors and making some changes within the computer code, the system can be used to measure the acidity and alkalinity of different solution samples. The standard deviation and the correlation coefficient of these results show high linearity of the constructed device, though the sensitivity of the imported pH meter is higher because it could measure up to three decimal places while the fabricated measures up to two decimal places. A pH meter based on the PIC16F877 microcontroller has been fabricated and used to test water and different solutions and the results are reproducible being displayed on a LCD.

References


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