

Electronic Circuit Design for Hydrogen Ion Measurement System

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ABSTRACT

This paper aims to study electronic design circuit for the hydrogen ion measurement system in chemical analysis and environment fields, to detect the pH of the subjected solution.

Electronic design building up on operational amplifiers LM 324 and LF444.

The practical experiment is done by glass electrode transducer. The design has been tested and calibrate by four standard buffer solutions and five kinds of aqueous solution. and pH 10) were intended to 9.2 These four standard solutions (pH 4, pH 7, pH cover the range for detection of acidity or alkalinity value through out the measuring range and obtained the desired results. The results obtained by electronic design are reasonable when compared to other pH meter system.

INTRODUCTION

The concept of pH was introduced by Sorensen in 1909. (D.V.S, (1999). He recognised that hydrogen ion concentrations, as distinct from total acidities, are frequently of importance in chemical processes. While studying enzymatic reaction, he found it convenient to define a symbol which could represent the concentration of hydrogen ions and called this symbol as pH.

The measurement of the hydrogen ion (pH) activity in a liquid solution; is one of the most common forms of analytical measurement in industry, because pH has a great effect on the outcome of many chemical processes. Food processing, water treatment, pharmaceutical production, steam generation (thermal power plants), and alcohol manufacturing are just some of the industries making extensive use of pH measurement and control (Thomas, 2006).

Hydrogen ion is also a significant factor in the corrosion of metal pipes and a vessel carrying aqueous (water-based) solutions, so pH measurement and control is important in the life-extension of these capital investments.

In order to understand pH measurement, you must first understand the chemistry of pH (Khandpur, 2004).

1. Chemistry of Hydrogen Ion:

Hydrogen ion activity in aqueous (water-based) solutions is a very important parameter for a wide variety of industrial processes. Hydrogen ions are always measured on a logarithmic scale, and referred to as pH. Free hydrogen ions (H^+) are rare in a liquid solution, and are more often found attached to whole water molecules to form a positive ion called hydronium (H_3O^+). However, process control professionals usually refer to these positive ions simply as “hydrogen” even though the truth is a bit more complicated (Mary, *et al.*, 1994).

Hydrogen ion is mathematically defined as the negative common logarithm of hydrogen ion activity in a solution.

$$pH = -\log a_{H^+} ; \text{ where } a_{H^+} \text{ is the activity of } H^+ \dots\dots\dots \text{Eq (1)}$$

Hydrogen ion activity is expressed as a molarity (number of moles of active ions per liter of solution), with “pH” being the unit of measurement for the logarithmic result:

$$pH = -\log[H^+]\dots\dots\dots \text{Eq (2)}$$

For example, an aqueous solution with an active hydrogen concentration of 0.00044 M has a pH value of 3.36 pH.

Water is a covalent compound, and so there is little separation of water molecules in liquid form. Most of the water molecules remain as whole molecules (H_2O) while a very small percentage ionizes into positive hydrogen ions (H^+) and negative hydroxyl ions (OH^-). The mathematical product of hydrogen and hydroxyl ion molarity in water is known as the ionization constant (K_w), and its value varies with temperature (Tom, 2006).

At 25 degrees Celsius (room temperature), the value of K_w is 1.0×10^{-14} . Since each one of the water molecules that does ionize in this absolutely pure water sample separates into exactly one hydrogen ion (H^+) and one hydroxyl ion (OH^-), the molarities of hydrogen and hydroxyl ions must be equal to each other. The equality between hydrogen and hydroxyl ions in a pure water sample, Means that pure water is neutral, and that the molarity of hydrogen ions is equal to the square root of K_w :

$$[\text{H}^+] = (K_w)^{1/2} = (1.0 \times 10^{-14})^{1/2} = 1.0 \times 10^{-7} \text{ M}$$

Since we know pH is defined as the negative logarithm of hydrogen ion activity, and we can be assured all hydrogen ions present in the solution will be “active” since there are no other positive ions to interfere with them, the pH value for water at 25 degrees Celsius is:

$$\text{pH of pure water at } 25^\circ\text{C} = -\log (1.0 \times 10^{-7} \text{ M}) = 7.0$$

As the temperature of pure water sample changes, the ionization constant changes as well.

Increasing temperature causes more of the water molecules to ionize, resulting in a larger K_w value. This means that while any pure water sample is neutral (an equal number

of positive hydrogen ions and negative hydroxyl ions), the pH value does change with temperature, and is only equal to 7.0 at one particular temperature. Pure water will be 6.51 pH at 60° C and 7.47 pH at freezing.

2. Hydrogen Ion Electrodes

In the field of chemical analysis, electrochemical techniques based on various phenomena occurring within an electrochemical cell are very much favored for application in laboratory and industry. The concentration of a component in solution is measured in terms of the effect it has on the electrical properties of the cell. The effect of the component on an electrode introduced into the solution forms the basis of the electrochemical transducer of the active type and the emf developed between the two electrodes of the cell constituted for this purpose is used to signify the concentration level. Most often used pH electrodes are glass electrodes shown figure (1). Typical model is made of glass tube ended with small glass bubble. Inside of the electrode is usually filled with buffered solution of chlorides in which silver wire covered with silver chloride is immersed. pH of internal solution varies for example it can be 1.0 (0.1M HCl) or 7.0 (different buffers used by different producers).

Active part of the electrode is the glass bubble. While tube has strong and thick walls, bubble is made to be as thin as possible. Surface of the glass is protonated by both internal and external solution till equilibrium is achieved. Both sides of the glass are charged by the adsorbed protons, this charge is responsible for potential difference. This potential in turn is described by the Nernst equation and is directly proportional to the pH difference between solutions on both sides of the glass.

The potential E is given by the Nernst equation.

$$E = E^0 + (RT/nF) \ln a \dots\dots\dots \text{Eq (3)}$$

Where

E = observed potential (emf)

E^0 = standard electrode potential (emf)

R= molar gas constant (8.314 J/mole per K)

T= absolute temperature in K(25°C=298K)

- n= number moles of electrons transferred
- F=Faraday's constant (96.478 Q/Eq weight)
- In= log to base e (natural log)
- a= activity of the ion

At 25°C, with conversion of the natural to log₁₀ and insertion of the value for R and E this equation simplifies to

$$E = E^0 + (0.0591/n) \log_{10} a \dots\dots\dots \text{Eq (4)}$$

From this equation, it can be seen that voltage (59.1mV/pH) depends on activity of the ion a change in ion activity will change the measurable voltage. The activity of an ion can be determined by a difference in voltage.

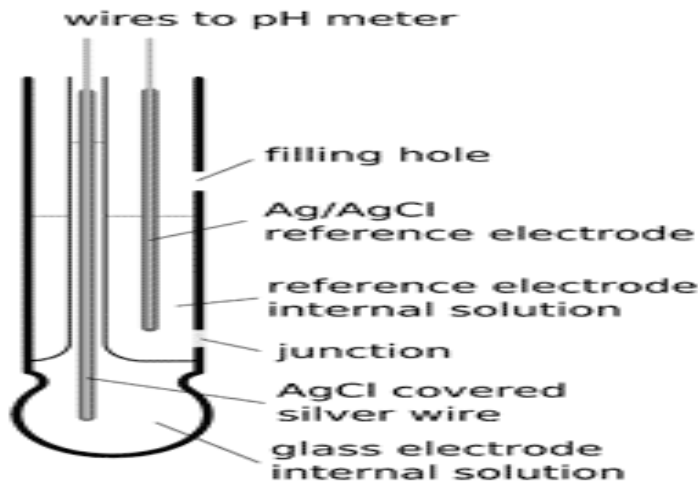


Fig (1) Combination Glass Electrode

MATERIAL AND METHODS

A very important measurement in many liquid chemical processes (industrial, pharmaceutical, manufacturing, food production, etc.) is that of pH: the measurement of hydrogen ion concentration in a liquid solution. A solution with a low pH value is called

an "acid," while one with a high pH is called a "base." The common pH scale extends from 0 (strong acid) to 14 (strong base), with 7 in the middle representing pure water (neutral). See figure pH scale (2).

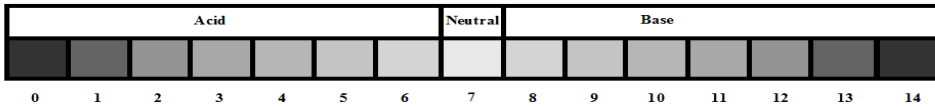


Fig (2): Hydrogen Ion Scale

1. Practical design

The specific design challenges of the pH electrode impose the need to select an amplifier which does not degrade the overall system performance. It is best to start with an understanding of what amplifier parameters contribute most to the voltage error in a pH electrode application. The most significant parameter to consider is the amplifier's input bias current. This is because even a small input bias current can produce a large voltage error when injected into the very high impedance of a pH electrode. Figure (3) shows the practical electronic design for the hydrogen ion measurement system. The design consist of a combined electrode and amplifier circuit.

1. 2 Combined electrode

Since it is easier to handle one electrode instead of two, combined electrodes are very popular. The indicating glass electrode and the reference electrode are simply built into a single physical entity. This helps to ensure that the two electrodes have the same temperature during operation. Combined electrodes with symmetrical electrode chains are the optimal construction for obtaining temperature equality in the two electrodes. In these electrodes the inner electrode of the glass electrode is the same type (Ag/AgCl) and has the same dimensions as the reference electrode, and the inner solutions are as identical as possible (saturated with KCl).

The source impedance of a pH electrode is very high because the thin glass bulb has a large resistance which is typically in the range of 10 M Ω to 1000 M Ω . This means that the electrode can only be monitored by high impedance measuring device (LF444).

1.2.1 Amplifier Circuits

The operational amplifier is a very widely used element in signal condition and processing circuits. An approach to building circuits is to suppose initially that amplifiers have characteristics as follows:

- High gain so that circuit gain can be set by external components.

- Very high input impedance, so that current flow into the inputs is negligible.
- Very low output impedance.

In the practical experiment are used two chips operational amplifier LF444 (high input impedance) and LM324. The amplifier details as the following.

Unity Gain Follower (A1)

Use as buffer signal from combined electrode (V_{in2}). The most important features of the voltage follower configuration are its very high input impedance and its very low output impedance. These features make it a nearly ideal buffer amplifier for interfacing high impedance sources and low impedance loads.

Differential Amplifier (A2)

The output of the differential amplifier is

)4 $V_{out} = (R_2/R_1)(V_{in2}-V_{in1}) \dots\dots\dots \text{Eq (}$

$$V_{out} = (100/10)(V_2 - 0) = 10 \times V_{in2}$$

The input voltages should not exceed operational amplifier supply voltage.

Summing Amplifier with unity Gain (A3)

The output of the summing amplifier is the sum of the input voltages. The sum of) 5the inputs should not exceed power supply. A general expression is given in equation (for a unity gain summing amplifier.

)5 $V_{out} = -(V_{in2} + V_{in1})\dots\dots\dots \text{Eq (}$

$$V_{out} = -(V_{in2} + 7)$$

The previous equation shows that the output voltage has the same magnitude as the sum of the two input voltage but with a negative sign, indicating inversion.

Unity Gain Inverter (A4)

Use as buffer and to convert negative output voltage to positive output voltage.

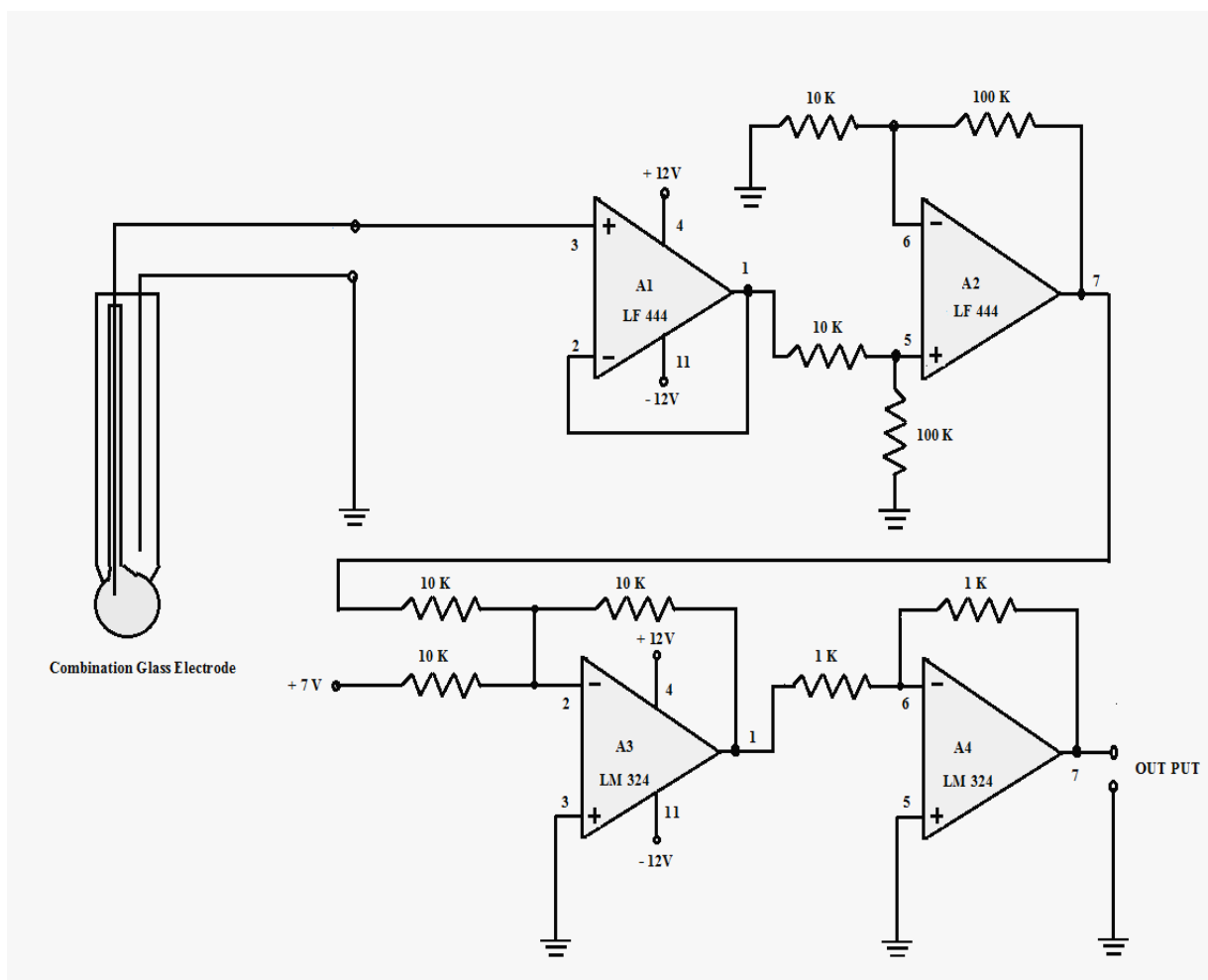


Fig (3) Practical Electronic Design Circuit

RESULT AND DISCUSSION

The theme of this paper can have a wide scope of research. This design can be applied in so many fields, medical, industrial, pharmaceutical, food production, and manufacturing.

The main results of this paper are divided in two parts

1. Calibration Result

To measure hydrogen ion concentration correctly, the electrode and transmitter circuit set need to be calibrated with buffer solutions. A buffer solution is a solution of special composition, which is able to resist change in pH that occur if small range in pH. When the combined electrode is immersed in a solution the glass electrode produces millivoltage per pH unit at 25 °C.

The following table (1) and (2) shows response hydrogen ion measure result with different calibration standards solution by used two glass electrode(x) and (y). Use two types of glass electrode for comparison the results of design and knowledge of precision. These different standard solutions were intended to cover the range for detection of acidity or alkalinity value through out measuring range. Figures (4) show that as the pH of the solution increases, the voltage produced by the pH measuring circuit decreases.

2. Calibrate Electronic Design Circuit

The following table (3) describes design circuit calibration result by the resistor (50 Ω). To calibrate the design circuit connect resistor 50 $\Omega \pm 1\%$ to the input transmitter. This resistor input to the electronic circuit gives it a 0.0 mV signal, equivalent to pH 7.00. This step necessary if you are checking the design circuit or are not sure you have a good electrode.

Table (1) Calibration Result by Electrode (X) at 25 °C

Standard Solution	Glass Electrode (X) output Result	Electronic Circuit Result				
		A1	A2	A3	A4	Output
pH 4	+165mV	+165mV	+1.8V	-9.4V	+9.42V	+8.8V
pH 7	-8mV	-8mV	-100mV	-7.5V	+7.46V	+6.9V
pH 9.2	-128mV	-128mV	-1.44V	-6.24V	+6.22V	+5.6V
pH 10	-170mV	-170mV	-1.9V	-5.7V	+5.69V	+5.1V

Table (2) Calibration Result by Electrode (Y) at 25 °C

Standard Solution	Glass Electrode (Y) output Result	Electronic Circuit Result				
		A1	A2	A3	A4	Output
pH 4	+185mV	+185mV	+2V	-9.7V	+9.68V	+9.1V
pH 7	+8mV	+8mV	+97mV	-7.7V	+7.68V	+7.1V
pH 9.2	-115mV	-115mV	-1.2V	-6.35V	+6.3V	+5.8V
pH 10	-153mV	-153mV	-1.7V	-5.91V	+5.92V	+5.3V

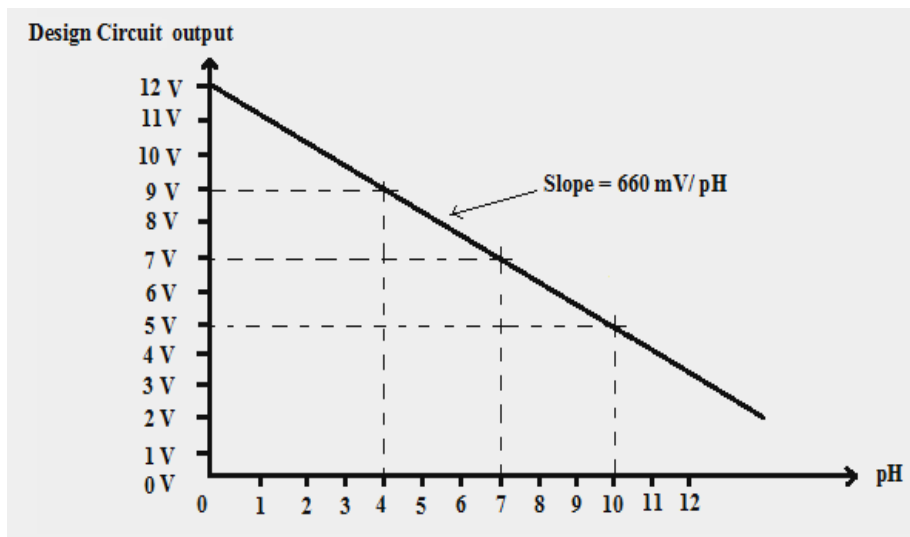


Fig (4) Calibration linear slope of output voltage versus pH value

Table (3) Design circuit calibration result

Resistor	Electronic Circuit Result				
	A1	A2	A3	A4	Output
50 Ω ±1%	-0.2mV	-2.01mV	-7.6V	+7.61V	+7.01V

3.2 The Result of Measuring Aqueous Solution

Table (4) explains the result of aqueous solution measurement. Performed this is measurement on different samples of water from different sources to know the value of hydrogen ion concentration.

Table (4) Aqueous Solution Result

Aqueous Solution	Glass Electrode (Y) output Result	Electronic Circuit Result				
		A1	A2	A3	A4	Output
Distilled water	+17.4mV	+17.4mV	+190mV	-7.8V	+7.81V	+7.3V
Drink water	-9 mV	-9mV	-104mV	-7.5V	+7.5V	+6.9V
Sea water	-51mV	-51mV	-576mV	-7.05V	+6.5V	+5.8V
Sodium hydroxide	-160mV	-160mV	-1.65V	-5.96V	+5.9V	+5.3V

CONCLUSIONS

The application of the practical electronic design for the hydrogen ion measurement system suitable in the construction of a portable analyzer for water quality monitoring, providing in site water analysis without the necessity of sampling and sample preparation. These systems are dedicated to environmental pollution survey of wastewater and natural water resources.

When designing with a pH electrode, as with any sensor, it is important to understand the sensor characteristics and how they affect a specific application. These characteristics include whether the sensor is active or passive, unipolar or bipolar, and whether it has a voltage or current output. Sensor sensitivity, linearity, full scale range, and source impedance should also be considered.

Hydrogen ion measurement system has to be calibrated against solutions of known pH values. For proper calibration, buffer solutions of carefully selected accuracy and pH range are required. The calibration should be performed using three or two buffers whose values bracket the expected value of the samples being measured. When carrying out the calibration the following points should all be borne in mind.

First- Electrodes should never be allowed to run dry because this will create static charges on the glass membrane resulting in a very sluggish response

Second- Cleaning of the electrode between buffers and sample or from sample to sample should be carried out by a jet of water from a wash bottle, followed by careful

rinsing with the buffer or sample to be measured. For very accurate work it is recommended to repeat the zero calibration after slope adjustment.

If the measuring solution is grounded (e.g. through pipes or stirrers), the practical electronic design must be isolated from ground.

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المخلص

تهدف الورقة لتصميم دائرة الكترونية لقياس الاس الهيدوجني في المجالات التحاليل الكيميائية و البئية والذي يمثل الاس الهيدوجني اهمية فى تلك المجالات. LM 324 و LF444 - يعتمد بناء الدائرة الالكترونية على دوائر المكبرات التشغيلية من نوع Combination Glass Electrode Transducer.- المحساس المستخدم في هذا الورقة من نوع وبعض المحاليل المائية .

- تم اختبار ومعايرة عمل الدائرة الالكترونية بواسطة اربعة محاليل قياسية
- هذه المحاليل القياسية كافية لاختبار عمل الدائرة الالكترونية لقياس المحاليل الحمضية و القاعدية
- النتائج التى تم الحصول عليها بواسطة التصميم مقبولة بالمقارنة مع غيرها من نظم قياس الاس الهيدوجينى