

Development of New Technique for the Continuous Monitoring Of Chlorine in Drinking Water

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ABSTRACT: It is necessary to measure the chlorine level in the water before its use for the drinking purpose. An automated method for routine measurement of chlorine level in water has been developed using photovoltaic detector coupled with a monochromatic pink colored light emitting diode as a source of light. The detected signal has further conditioned and processed by the operational amplifier and ARM processor respectively. The software has been developed for the functions-adjustment of 100% transmittance for reference, measurement of transmitted light intensity and its conversion into absorbance, look-up table of optical densities of standard solutions, and finally estimation of unknown concentration. Conventional colorimetric method were simplified for this technique. The technique has the advantage of continuous monitoring and low detection limit. The analyzer based on the present technique has been successfully used for the monitoring of chlorine level. The analyzer is handheld and suitable for the field work.

KEYWORDS: Chlorine, drinking water, optical density, continuous monitoring.

I. INTRODUCTION

Chlorine (Cl) is an important element of the halide group and plays an important role in disinfecting the drinking water. The main problems with drinking water are related to faeces and chemical contamination from man-made sources [1,2]. The existence of microbiological organisms particularly bacteria and viruses is a main cause for the spread of water-borne infective diseases. Similarly, presence of some organic and inorganic compounds is a major worry due to their toxicity to animal life [3,4]. There is a need of proper treatment of water before its distribution to community. The disinfection of water is necessary to control the spread of water-borne diseases [5]. Filtration and distillation techniques are used for the water disinfection. But they are not economical for the treatment of large quantity of water. On the other hand chlorination is simple and economical method of disinfection. Chlorination of water or wastewater is performed to destroy microbiological organisms and also to oxidize organic substances. Upon introduction to water, chlorine gas will form hypochlorous acid (HOCl) and hypochlorite ion (OCl⁻). The term "free available chlorine" refers to the concentration of hypochlorous acid plus hypochlorite ion in the water. Chlorination has many advantages as a disinfectant, including its efficiency and on site measurement. Another advantage is that chlorine leaves a disinfectant residual that helps in preventing recontamination during storage. The dose rate of chlorine depends on the quality of water. The over dose of chlorine can cause the additional effects. The lack of a chlorine residual in the water may indicate the possibility of post treatment. It is required to measure the chlorine level for the optimization of dose rate. An automatic, handheld and battery operated analyzers are more suitable to measure the chlorine level at multiple places of centralized water distribution system.

The laboratory methods for the chlorine analysis include idiometric techniques, amperometric titrations, and colorimetric procedures using reagents. On-line methods are typically an automated version of one of the standard methods. Microcontroller (μ C) is used in the automation of measurement and control section of analytical instruments [6]. It is a small capacity single chip computational system used for the dedicated applications. The benefits of μ C based systems are numerous; low cost, portable, continuous monitoring, less manual operations, etc. A variety of cross-compilers are available for a particular microcontroller, allowing the user to write programs in a universal high level language, such as C and JAVA instead of its native tedious assembly language.

The objectives of the present work were (i) to design and built electronic circuit of the μ C based chlorine analyzer and

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(ii) development of the software for the control and measurement of the incident and transmitted light respectively, preparation of the look-up table of calibration data, and calculation of unknown concentration. The rest of the paper is organized as follows: The method of chlorine analysis is discussed in section II and system design of electronic circuit is discussed in section III. The system software development is discussed in section IV. The results are discussed in section V. Finally, the conclusions and future scope are discussed in section VI.

II. METHODS

If a reference solution, which does not absorb light, is in the sample holder, then following equation relates the light transmitted to the intensities of the light [7].

$$T = \frac{I}{I_0} = 1, \text{ and } I_0 = I \dots \dots \dots (1)$$

Where T is transmittance; I_0 and I are incident and transmitted intensities respectively.

When a solution contains a colored species, then it absorbs light I_A , i.e., less light is transmitted. Thus, equation 1 becomes, $I_0 = I + I_A$, $I = I_0 - I_A$, $I < I_0$ and $T < 1$

The chemical compounds have a characteristic wavelength of light they absorb. Therefore, the color transmitted depends on the color absorbed. The less light transmitted by a solution, the more concentrated is the solution.

The Beer-Lambert's Law [8,9] quantitatively expresses the relationship between the amount of light absorbed and the concentration of the solution. This law uses the following relationship: $A = \epsilon cd \dots \dots \dots (2)$

Where: A = Absorbance, ϵ is Molar extinction coefficient; units - $L \text{ mole}^{-1} \text{ cm}^{-1}$, c is concentration; units - mole L^{-1} , d = optical path length; unit - cm, ϵ is constant for a given species in a given solvent at a specific wavelength.

Practical application of the Beer-Lambert's Law comes in determining the unknown concentration of light-absorbing solutions. The equation 1 can be simplified as:

$$c = \frac{A}{\epsilon d} \dots \dots \dots (3)$$

The path length, d, is constant. Since the value of ϵ depends on number of parameters, the unknown concentration of a species in solution is obtained by comparing the absorbance of the unknown with the absorbance values of species of known concentrations at the characteristics wavelength, λ_{max} . In practice, a calibration curve of absorbance at λ_{max} versus the known concentrations of standard solutions is plotted as shown in Figure 1. The equation of curve can be obtained by rewriting eq. 2,

$$A = (\epsilon d) \times c + 0 \dots (4)$$

$$Y = mx + b \dots \dots \dots (5)$$

Comparison of eq. 4 and 5 proves that the curve shown in Figure 1 is linear and passes through the origin. It indicates that, using calibration curve, the unknown concentration of a solution can be determined. In addition, the calibration curve can be used to determine an extinction coefficient by taking ratio of the slope and d.

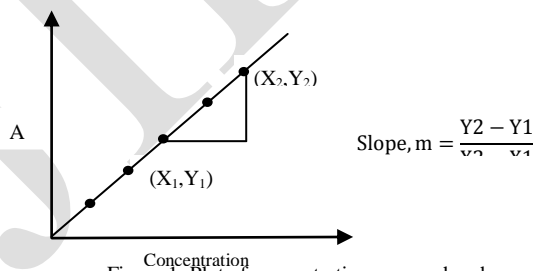


Figure 1: Plot of concentration versus absorbance (A)

III. SYSTEM DESIGN

The main units of the system are : power supply, forward bias voltage control, sample holder, signal conditioning, signal convertor and processing unit. The complete circuit diagram of the chlorine analyzer are shown in figure 2. Each unit of the circuit diagram is explained in the next section.

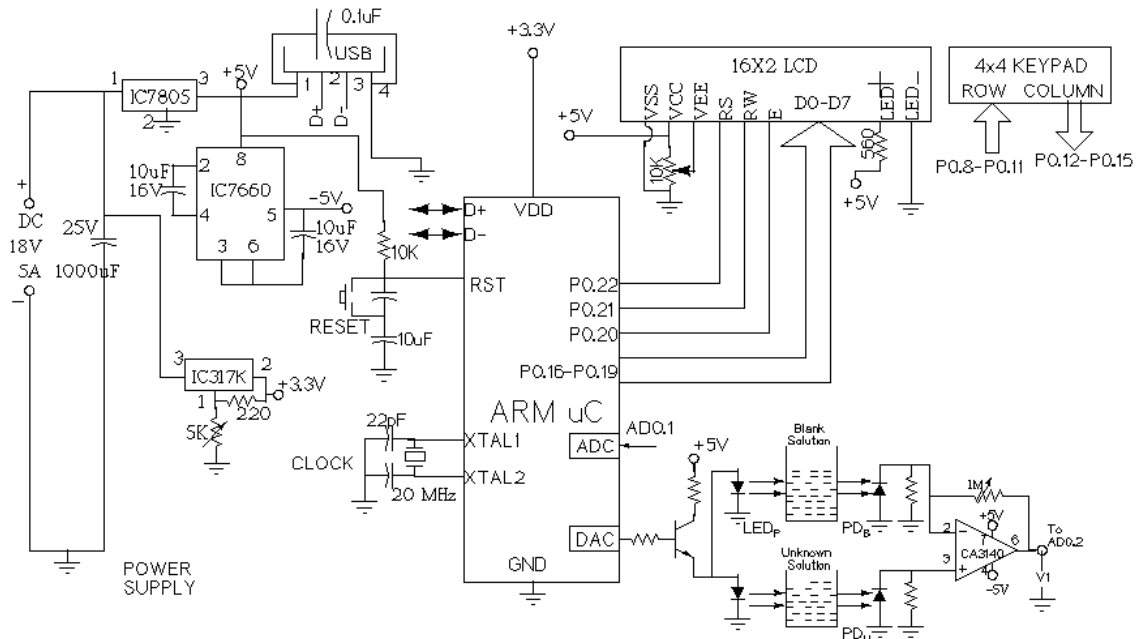


Figure 2: Circuit diagram of the chlorine analyzer.

A. Dc Power supply unit

A 12V voltage with 5 Amp current capacity produced by switch mode power supply is the source of electric power. It also works on 9 V non-rechargeable battery cell. Most of the components in the circuit are designed to operate at a 5 V supply, and an IC 7805- 5 V voltage regulator is used to convert the battery voltage to a stable 5 V supply. The capacitor is connected across the output to eliminate the high frequency noise. An adjustable LM317- 3.3 V regulator is used to provide a supply voltage to the ARM processor. The requirement of dual power supply for the operational amplifier (OP-AMP) is satisfied by IC 7660 which is used to convert the +5V to -5V supply.

B. Forward bias control unit.

It is a on chip programmable digital to analog convertor (DAC) circuit which drives the LED in forward bias mode. The medium power NPN transistor, TIP 122 is used in the emitter follower configuration and works as a buffer. The light produced by LED is changed by controlling the output of DAC which is applied to the LED. It adjusts the transmittance for blank solution at 100 %.

C. Sample Holder

It is made from borosilicate glass. The glass should be as thin as possible, so that attenuation of light is minimum. LED is fitted at one side of sample holder and its light is made to shine through the sample placed in sample holder. The transmitted light passed through the sample, struck the opposite side of the sample holder where photodiode is mounted[10].

D. Signal conditioning unit

The incident light with intensity I_0 is passed through the sample. Some part of it absorbed by the sample and remaining with intensity of I is transmitted. As the transmitted light strikes the photodiode, photocurrent I_{pd} is generated. The photocurrent is converted into voltage by resistor. The relative absorption is obtained with the use of difference amplifier which takes the difference between transmittance by blank and unknown sample. It is a high gain amplifier with very low input bias current. The FET input operational amplifier, CA 3140 is selected to construct the amplifier. The output voltage of photodiode is given by [10],

$$V_{out} = I_{pd} \times R.$$

Where I_{pd} is the photo current in μA , R is the resistor used for current to voltage convertor.

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E. Signal convertor and processing unit

ARM LPC 2148 processor is used as signal convertor and processor. It is powerful and easy to program RISC controller. Its main features are low power consumption and on chip 10 bit ADC and DAC. The on-chip ADC converts the analog signal V_A into digital signal. DAC produces the analog voltage for driving the LED. It also manipulates the digital signal into absorbance and concentration.

F. Signal display unit

It is an alphanumeric 16 x 2 LCD used in the 4 bit mode. The processor has the function of analyzing data and displaying it on the LCD.

IV. SYSTEM SOFTWARE

The software has been developed in the C language using the Keil Integrated Development Environment. The compiled code (HEX file) has downloaded into Flash memory of processor ARM LPC 2148 by the LPC 2000 utility in the in system programming mode. The flow chart is depicted in Figure 3, which shows the sequence of steps involved in the software development. When the system is activated, it will invoke the processor to reset all hardware devices in a normal mode. The preloaded program is then executed and performs following functions.

1. Analog voltage generation for the adjustment of 100 % transmittance for the blank solution.
2. Calculation of absorption from transmittance.
3. Preparation of the look-up table of standard solutions.
4. Calculation of slope from the look-up table data.
5. Estimation of unknown concentration from the slope and absorption.

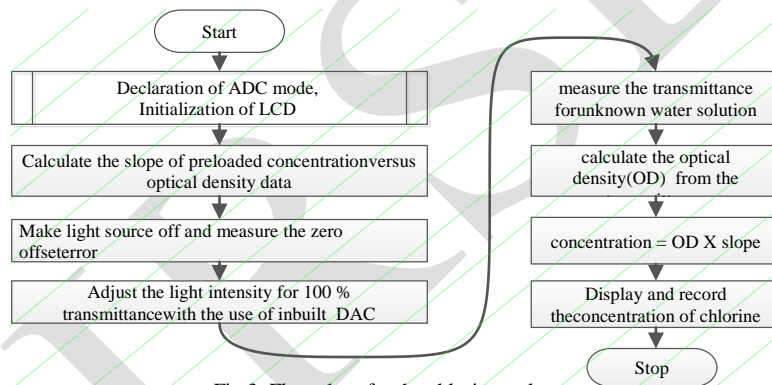


Fig.3: Flow chart for the chlorine analyzer

V. RESULTS AND DISCUSSION

The internal registers and external peripheral devices are set at default state by the system reset. Then the preloaded program converts the digital voltage into analog to drive the pink colored LED of peak wavelength of 410 nm. The light detected by the photo diode is converted into voltage and measured and, analog into digital value. Initially it adjusts the transmitted intensity for blank solution at 100 %. After that it measures the transmittance of unknown chlorine solution.

The amount of chlorine present in the water is determined in terms of iodine [11,12,13]. The absorbance of various concentrations of iodine and unknown amount of chlorine in water are shown in Table I. Five different concentrations of I_2 solutions were prepared. Using highest concentration solution of I_2 , λ_{max} was determined and it was found to be 410 nm. At this λ_{max} , absorbance of different known concentration solutions of I_2 as well as unknown concentration solution of Cl_2 were measured and depicted in Table I. The graph of concentration versus absorbance is shown in Figure 4.

ml of 0.005M I_2 solution	Volume in ml	Conc. of I_2 $10^{-4}M$	Absorbance at $\lambda_{max}=410nM$
0.5	25	1	0.125

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1.0	25	2	0.320
1.5	25	3	0.502
2	25	4	0.781
2.5	25	5	1.0027
Cl ₂	25	Unknown	0.342

Table I. Absorbance for the known concentrations of I₂ and unknown Cl₂

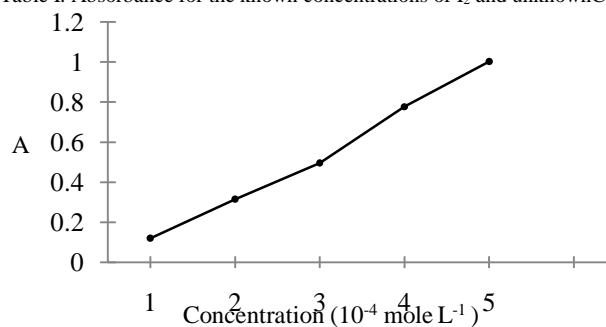


Figure 4: Calibration curve of Conc. Vs Absorbance (A) for finding the concentration of unknown chlorine solution.

For a given unknown solution the measured absorbance is 0.342. The concentration of unknown chlorine solution is determined from the calibration curve as shown in Figure 4. The estimated value of unknown concentration from the curve is found to be 2.3×10^{-4} mole L⁻¹.

VI. CONCLUSIONS

The present work describes the chlorine analyzer which uses a pair of LED and photodiode to transform the unknown concentration of chlorine in water into analog voltage signal. This signal is further converted into digital signal and manipulated into concentration value of chlorine by the ARM processor unit. The developed device is low cost, portable, and easy to operate. Since it is capable of being operated by small dry battery, it is suitable for the field work. It has been successfully used for the measurement of concentration of Cl₂ in water solution. The device can be used for the detection of some other similar type of chemical species in water.

Future scope: It can be interfaced to the PC for the data collection and analysis. The battery charger circuit can be included in the analyzer for the use of rechargeable battery.

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BIOGRAPHY



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