A Novel Optical Sensing Technique for Detection of Fluoride in Ground Water of Guwahati

Tridiv Medhi, Tipu Kumar Prithani, Parismita Das, Bikramjit Goswami and Shakuntala Laskar

Abstract: This paper presents the design of a novel optical sensor for detection of anions such as Fluoride present in ground water of Guwahati city of the North Eastern India. The penetrating property of laser is taken as the base to perform the experiments for designing of the sensor. The experimental set up is made with a laser source, detector and the sample of ground water used in between the source and the detector. The partially absorbed light from the sample is detected using a photo detector and simulated using labVIEW. The complete setup is based on the intensity-voltage relationship obtained at the photo detector.

Keywords: Fluoride, laser, optical sensing, photo detector.

I. INTRODUCTION

Approximately half of the world's population lives in urban areas and by the year 2025 will have risen to 60 per cent, comprising some 5 billion people. Rapid urban population growth and industrialization are putting severe strains on the water resources and environmental protection capabilities of many cities particularly in developing nations. The lack of source of clean drinking water is giving birth to public health concern worldwide. Waterborne diseases are a consequence. Access to safe drinking water is essential to health, a basic human right and a component of effective policy for health protection. Human use of fresh water has registered a 35 fold increase in the last 300 years.

Ground water is generally considered as a safe source of fresh drinking water. But the contamination of ground water is not away from the evils of modernization. Ground water is assumed to be of higher quality unlike surface water sources as it remains unexposed but with the increase in domestic sewage and agricultural and other industrial wastes the natural sources are getting contaminated every now and then.

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The chronic impact of these chemical contaminants of drinking water is dreadful. They cause very serious health problems, whether the chemicals are naturally occurring or derived from source of pollution [11].

India is currently facing critical water supply and drinking water quality problems. There is evidence of prevailing contamination of water resources in many areas of India. Although information on drinking water quality of Northeastern India is very little, results reported by various agencies have been alarming. Available literature shows that groundwater in Assam are highly contaminated with iron. The occurrence of fluoride contamination in Darrang, Karbi Anglong, and Nagoan districts of Assam in the form of fluorosis were already reported. High level of fluoride and iron distribution in groundwater sources of certain districts of Assam has also been observed. The health problems arising as a result of fluoride contamination are far more widespread in India. Nearly 177 districts have been confirmed as fluoride-affected areas [11].

A recent survey showed that 18 districts in Assam have become prone to arsenic and fluoride contamination triggering alarm. But it's not the only area where we found ground water contaminated. Almost 16 per cent of city areas and suburbs were also affected. Fluoride and arsenic contamination can cause serious health problems, as reported by United Nations International Children Emergency Fund during its fluoride and arsenic mitigation programme recently [12].

Accurate measurement of chemicals such as heavy metal ions and anions in water has acquired great practical significance because of the toxic effects these chemicals may cause in humans. Development of simple, sensitive, low-cost, light weight sensors capable of direct measurement of water pollution is of considerable interest to all. The main focus is on designing a sensor based on all these attributes in the project. The paper emanates out of that focussed project endeavour [6].

Fluoride compounds present in water causes a major health disease and hence their detection is very important in the process of pollution monitoring. The safe level of Fluoride concentration in ground water is between 0.5 and 1.0 mg/L (according to World Health Organisation standards). Fluoride concentration above 1.5 ppm level is unsafe and can cause diseases like Fluorosis and dental disorders. So, it is desirable to have a simple, handy and layman's sensor for measurement of Fluoride content in water, as it is found in many parts of the North East India's ground water [9].

A recent study shows 28,181 water sources located in Assam have been contaminated with fluoride and inorganic materials, followed by 2,931 in Tripura, 566 in Arunachal Pradesh, 136 in Nagaland, 124 in Meghalaya, 76 in Sikkim, 37 in Manipur and 26 in Mizoram [10].

The sensor designed for measurement of fluoride is based on the principle of intensity modulation through light interruption. A laser of certain wavelength is used as the source and a photo detector form the basic optical sensor system. Amount of light reaching the detector gives the measure of the pollutant content in the pre-calibrated sensor set-up. The amount of photons i.e. light falling on the photo detector is converted to change into analog voltage. The analog voltage signals from the sensors are converted to equivalent digital signals by analog to digital converter [8].

For Fluoride the wavelength of maximum absorption is 570 nm. The presence of fluorine in solution is detected when laser beam at the wavelength of 570 nm results in a decrease in the intensity of the light propagating in the sample medium. For small concentration levels of fluoride, the loss of the power of light is proportional to the amount of fluoride in the solution. That is, a change in the sensor output signal level is a linear function of the amount of fluoride. Similarly the same can be said for arsenic operated at 330 nm. To determine the sensitivity of the results and accuracy of the analysis the whole process can be simulated using the tools like labVIEW. The preliminary results establish the feasibility of detecting low concentration fluoride in water. Also it is found from the existing literatures that the optical sensing techniques are simple, low cost, acurate and user friendly. The main motivation of designing optical sensor for detection of water pollutants came from the definite merits seen from the existing literatures on the field and the urge to overcome the limitations found in some of the related existing chemical techniques [9], [10].

In this paper the design of the sensor system is discussed, the relation between light intensity and absorbance in the section II. The experimental details are presented in section III and the results are discussed and analysed in section IV.The paper is concluded in section V.

II. LIGHT INTENSITY, ABSORBANCE AND WAVELENGTH

The background principle behind the experimental work is dependent on the principles of laser i.e its wavelength and penetration and absorption in the media of air and water sample and the changes taking place in those parameters due to change in the concentration of the pollutant materials [7]. The most important parameter in this experiment is the wavelength of light source at which maximum absorption by fluoride takes place.

According to Beer-Lambart law, there is logarithmic dependence between the transmission (and or transmissivity), T of light through a substance and the product of the absorption coefficient of the substance, α, and the distance the light travels through the material (i.e., the path length), ℓ [1].

$$T = 10^{-\ell\alpha} \quad (1)$$

Also the transmittivity is related to

$$T = I/I_0 \quad (2)$$

where, I and I_o are the power transmitted with and without an absorbing medium, respectively.

The absorption coefficient, α can, in turn, be written as a product of either a molar absorptivity (extinction coefficient) of the absorber, ε, and the molar concentration c of absorbing species in a sample,

$$\alpha = c\varepsilon \quad (3)$$

Hence the power incident at the detector is givenas below.

$$I = I_0 . e^{\alpha\ell} \quad (4)$$

Finally the absorbance

$$A = -\log_{10} I/Io \quad (5)$$

The ever increasing demand for in situ monitoring of health, environment and security has created a need for reliable, miniaturised sensing devices. To achieve this, appropriate analytical devices are required. The use of light emitting diodes (LEDs) as light sources is one strategy, which has been successfully applied in chemical sensing. The same principle is applicable to detect pollutants such as fluoride in water.

III. EXPERIMENTAL DETAILS

The primary aim of the experimental set-up for detecting the level of fluoride in ground water is the optimization of the sensor design for making it portable and achieving higher sensitivities with greater accuracy. The design can be further upgraded to make it user friendly so that it is accessible to all at ease.

The penetrating property of laser is utilized in the detection process in the experiment. An experimental set up is made with a laser Light Emitting Diodes as source and the light ray is passed through the collected samples of ground water. Air is taken as the medium for transmitting light before and after it passes the sample. The partially transmitted light from the sample is utilized and detected using a photo detector which acts as photo-sensor.

In order to exploit the modulation of intensity characteristic of the light ray, the source, the sample and the detector are kept as close as possible; the point where detector output is maximum when light passes an empty glass container. The distance of the sample from the source is 10 cm. A test tube of 1cm diameter is taken to hold the sample and it is used throughout the experiment to maintain uniformity in results. After every test this tube is washed with distilled water. The test tube selected, is of good quality glass so that it absorbs minimum light and has good transmitting property. To hold the test tube in a fixed position and keep its alignment right a clamp stand is used. The experimental set-up used for the present investigation is shown schematically in figure 1. The light from a laser of wavelength 570 nm, is transmitted through air medium (neglecting losses). After getting passed through the sample, the light falls onto the detector, which digitally displays the obtained output voltage when connected to a multimeter. Depending on the chemical ions for analysis, the required wavelength of the source will vary.

For the experimental setup considered presently, the amount of absorbed light would depend on the concentrations of fluoride present in water. Due to absorbance, a part of light will be absorbed by the sample, and the remaining will fall on the photo-transducer. This is due to the absorptivity of fluoride particles. In the case of fluoride the absorbance is maximum when the light source is of 570 nm wavelength.

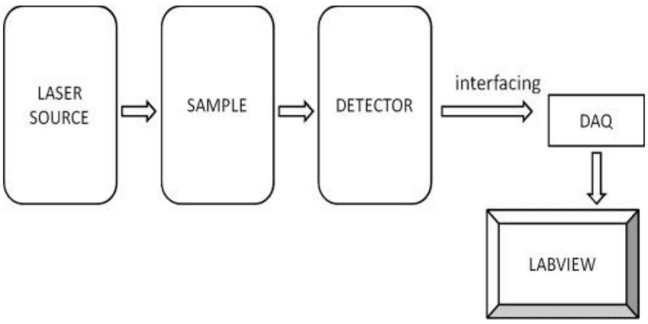

Fig 1. The experimental set-up used for measuring the fluoride concentration in ground water.

Standard test samples having chemical concentrations ranging from 0.001mg/l to 2mg/l are prepared by dissolving sodium fluoride in pure water. The reason for taking salt of sodium fluoride is that it gets fully dissolved in water. The samples are then allowed to mix uniformly for 4-5 hours, after which the measurements are carried out. When added to water, the NaF salt dissolute into sodium and fluoride ions. Since the wavelengths of light used is close to the peak absorption wavelength of the fluoride in the solutions, majority of the absorption are due to fluoride ions and it increases with the increase in chemicals' concentration.

After observing the outputs of the photo detector for all concentrations of the samples using a digital multimeter, the setup is then interfaced with LabVIEW through the DAQ for realtime monitoring of the voltage values with respect to time. A set was drawn beforehand in the workspace of LabVIEW where a filter has been used to filter out the noise and a numeric knob and a scope to observe the numeric value and the graph of voltage output respectively. The results were plotted for each concentration to obtain a standard curve. The basic slope equation obtained from the concentration (mg/l) versus detected voltage (mV) graph has been made use of to form the equation for concentration. This equation is applied in the LabVIEW to get real time value of concentration for any test sample. The same test procedure is performed for collected water samples from various water sources, first with predetermined quantity of the fluoride pollutants to check the sensitivity of the setup. These predetermined values were obtained by chemically testing the collected samples. When the sensitivity and accuracy of the method was set, the same test was performed for unknown quantity of any sample to determine the amount of pollutants i.e. fluoride in the given sample.

IV. RESULTS AND DISCUSSION

From the experimental result it is observed that the amount of absorption of light passing through the solution increases linearly with the increase in concentration of fluoride and arsenic in the solutions and accordingly the output voltage decreases. The readings of the experiment are tabulated in Table I.

Table I. Detector voltages obtained practically and theoritically in millivolts against concentration of fluoride and the error; when reference voltage using distilled water is 490 mV

Conc. of fluoride in distilled water (in mg/ml)	Detector output for fluoride (in mV) Practical	Detector output for fluoride (in mV) Theoritical	Error %
0.001	484.0	483.2	-0.165
0.005	483.5	482.8	-0.140
0.01	482.5	482.4	-0.020
0.02	480.5	481.5	0.207
0.05	478.0	478.8	0.167
0.10	475.0	474.2	-0.147
0.13	471.0	471.5	0.106
0.16	469.0	468.8	0.042
0.18	467.0	466.9	-0.012
0.20	465.0	465.1	0.026
0.23	462.5	462.4	-0.022
0.26	460.0	459.6	-0.072
0.30	456.0	456	0.000

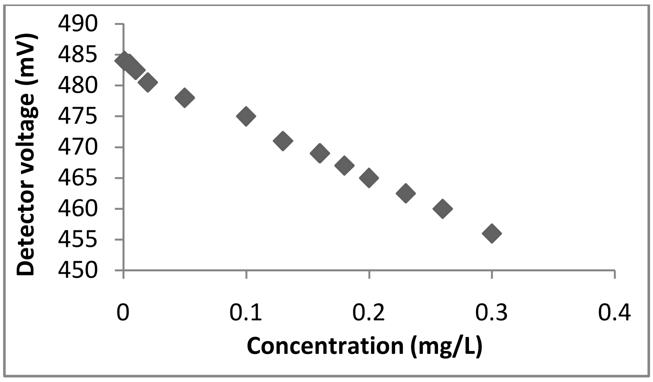

Fig. 2 Detector output (mV) versus concentration of absorbing species fluoride (mg/L)

Fig. 2 shows the output at the detector for different concentration of fluoride in water respectively. The graph for concentration (mg/L) versus detector voltage (mV) was plotted and a linear curve was obtained. From the relationship obtained, any unknown concentration of the absorbing species of fluoride in a sample of ground water from any source can be determined.

A water sample from the river Brahmaputra (at Kacharighat) was taken and tested to initialize the conclusive work. The sample was also chemically tested for validation of the results obtained by the optical sensing technique at Guwahati University chemical laboratory. Results showed that the value obtained in the optical sensor setup was 0.27 mg/l for a voltage of 459 mV approximately matched the value of 0.25 mg/l found by chemical analysis method. The values are tabulated in Table II.

Table II. Concentration obtained in the optical sensing technique and by chemical analysis for a water sample from river Brahmaputra

Concentration obtained from optical sensing technique (mg/L)	Concentration obtained by chemical analysis method (mg/L)	Percantage error
0.27	0.25	8.0

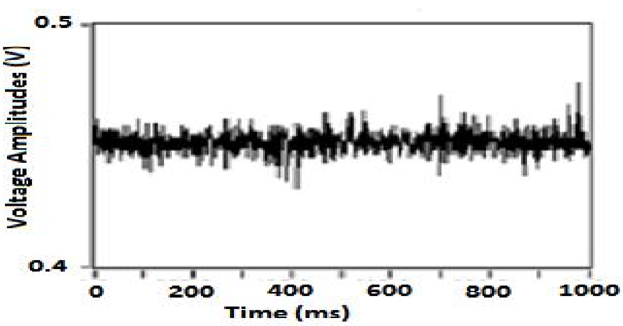

Fig. 3(a) Unfiltered detector voltage (V) obtained at labVIEW terminal versus time (ms).

The detector voltage curve at realtime obtained using Labview is shown in Fig. 3(a) while the filtered voltage for the same sample is shown in Fig. 3(b). The filtered voltage is obtained when the acquired signal by the DAQ is fed to a butterworth filter and then observed with a scope.

Results show that, the work plot produced a high degree of accuracy with the correlation coefficient R2 of 0.996 and a percentage error of 8%.

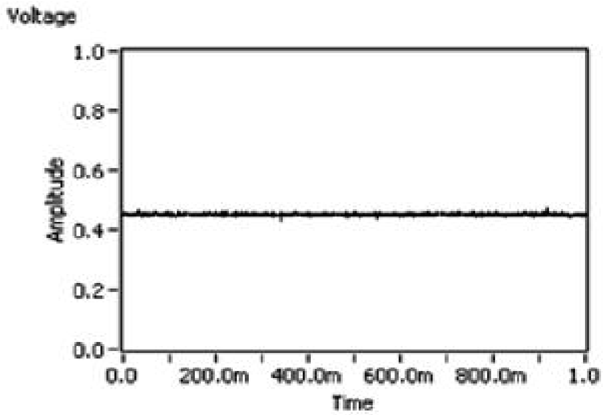

Fig. 3(b) Filtered detector voltage (V) obtained at LabVIEW terminal versus time (s).

V. CONCLUSION

The intensity of light from the source and the voltage obtained at the detector end forms a linear relationship as discussed in the paper for designing the sensor system for fluoride detection. Thus this is an intensity modulated optical sensor system with simple design and implementation. Unlike the conventional method that assesses ionic-strength and pH dependent fluoride ion activity in polluted water, the proposed sensors would directly measure fluoride levels.

It is also be possible to analyse and calculate the values of fluoride in water by interfacing the output of the transducer i.e., photodetector with computers. Smart detection processes using Artificial Neural Networks will be designed in the same project in the future work.

This newly developed optical sensor system produced a high degree of accuracy with the correlation coefficient (R^2) of 0.996. This study has proven that visible lasers are better for sensing water pollutants than the conventional chemical analysis methods. This new methodology is very useful for measuring the fluoride levels in water. The use of LabVIEW to acquire optical sensor data; and thus results obtained for real time monitoring of pollutants concentration using PC was encouraging.

The novel optical sensor can by optimally used for water pollution level information in Guwahati city and also equally at other places as it is versatile and one can test any heavy metal ion or any anion simply by varying the laser source rating. This sensor system can be used by many sectors such as tourism, environmental department; public sectors and others related sectors. This can be of great help in estimating fluoride content of water bodies in both urban and rural areas. Moreover the accuracy of the system has been found to be of industry standard with less than 10% error.

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