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Development of Microcontroller Based Portable Optical Instrumentation System for Measurement of BOD

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SK and JV conceptualized the stud. Authors JV, A, TT and HJS designed the hardware and software. Authors JV, SK, VS performed the statistical analysis. Authors HJS and TT developed and fabricated the hardware and implemented the software. Authors HJS and VS managed literature searches. Authors HJS, JV and SK wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To design, develop and fabricate a portable optical instrumentation system for the measurement of Biochemical Oxygen Demand.

Place and Duration of Study: The design and fabrication of the portable optical instrumentation system was conceptualized at Department of Chemistry and Department of Electrical Engineering J.N.V University, Jodhpur and fabrication was done at M/s Mindfield Technologies Pvt. Ltd., Jodhpur under the Instrument Development Program of DST, New Delhi.

Methodology: A portable optical transducer device with microcontroller embedded circuit has been designed for the measurement of dissolve oxygen (DO) and calculation of Biochemical Oxygen Demand (BOD). It comprises of three functional units viz., sensing unit, instrumentation unit and controller unit. A monochromatic light source is used to irradiate the prepared sample solution under test. A part of the incident light is absorbed by the solution under test and intensity of the transmitted light is measured on other end by the optical sensor. The change in light intensity is used to calculate the DO and subsequently report BOD on LCD display.

Results: A portable optical instrumentation system has been developed successfully and tested. The performance of the designed system has been assessed by means of statistical approach based on repeated measurement and obtaining standardization curve. The performance of the designed optical instrumentation system was validated by measuring the BOD values for standard Glucose-Glutamic Acid (GGA) solution and comparing them with those obtained from the standard Winkler's method; the results depicted a close agreement.

Conclusion: The developed portable BOD instrument is battery operable and compact for facilitating field use.

Keywords: Portable instrument for BOD; optical transducer for BOD; instrument design for BOD; microcontroller based optical instrument.

1. INTRODUCTION

Determination of biochemical oxygen demand (BOD) is important in quality assessment of waste waters, effluents, sewage treatment and a key test in sanitary engineering practices. The BOD is an indicator of biodegradable organic substances in water. It is measured as the amount of oxygen required by microorganisms while stabilizing the organic matter under anaerobic conditions. It has significant impact in the environmental pollution control including self-purification capability of water bodies. The BOD in natural unpolluted water is less than 5 mg/L. Its value for raw sewage may reach up to 500 mg/L and has to be brought down to 20 - 30 mg/L for recycling after treatment [1]. It is necessary to measure the dissolved oxygen (DO) levels over a five day incubation period for biochemical degradation of organic and inorganic materials such as sulphide and ferrous ions. The DO is the factor that determines whether the biological changes are brought out by aerobic or anaerobic organisms. The past few decade have witnessed the growing need for instrumentation based method for BOD determination. This has resulted in the development of procedures based on UV absorbance [2-5] and fluorescence [5,6] properties of waste water. An optical method for BOD determination has been developed by measuring the absorbance of 440 nm monochromatic light by the sample after adding Winkler's reagents and mathematical modelling for correlating absorbance and DO has been reported [7]. This paper communicates the design and fabrication of a portable optical transducer with microcontroller based system to read DO at predetermined wavelength and calculates the BOD based on the difference of DO values of 1st and 5th day.

2. EXPERIMENTALS DETAILS AND METHODOLOGY

The basic concept, hardware and software for the proposed BOD measurement and analysis system, named as BODMAS are discussed in the following sections.

2.1 Concept and Block Diagram

BODMAS is an optical transducer device with microcontroller based circuit and associated software to convert the analog input to its corresponding digital value. BODMAS comprises of three functional units i.e. optical transducer, instrumentation system and control system as shown in Fig. 1. A single wavelength LED based light source is mounted on one side of a designed testing vice and on the other end an intensity sensor is mounted. A combination of UV light source and on intensity sensor is used in the BODMAS as sensing unit. The light emitted by the UV LED of wavelength 440nm passes through the sample placed in testing vice.

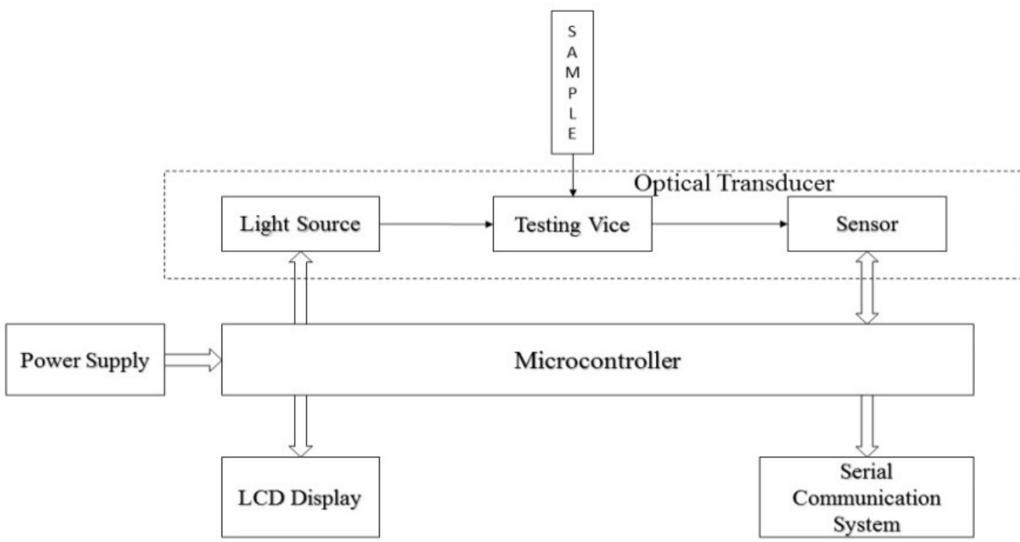

Fig. 1. Block diagram of BODMAS

Intensity sensor estimates the light absorbed by the sample through measurement of the transmitted light falling on the sensor. The output of the sensing unit is in the form of fixed frequency pulses proportional to the intensity of the light received. This is calibrated in terms of DO by the instrumentation unit. All parts of the sensing and instrumentation scheme are managed and controlled by the controller unit which is based on ATmega16 microcontroller [8] manufactured by Atmel Corporation, USA. It also serves as user interface for data communication with computer for further analysis and future use [9]. The measurement output is also displayed on an LCD Display [10] interfaced to the system. A testing vice is indigenously designed and fabricated by employing a 3D printer assembled in the research laboratory of M/s Mindfield Technologies Pvt. Ltd. It is fabricated from acrylic nitrile butadiene styrene plastic, thus ensuring that it is light weight. The testing vice serves as sample holder to hold the test tube containing the sample under test. This is designed in such a manner that it can be adjusted to hold cuvettes of a variety of sizes while ensuring that no ambient light can enter the sample. The colour of the sample holder is chosen to be black to minimize the effects of interference from ambient light.

2.2 Design of Hardware

The hardware comprises of three functional units viz. optical transducer, instrumentation system and control system, described in the following sections.

2.2.1 Optical transducer

The optical transducer consists of a single light emitting diode (LED) of wave length 440 nm which serves as light source with an optical intensity sensor placed at the diametrically opposite end.

2.2.1.1 Light source

The LED light source [11] is used to generate a fixed intensity light. A part of this light is absorbed by the solution under test. A study of absorbance at various wavelengths has been carried out by the researchers and wavelength value of 440 nm has been selected after analyzing the response to wavelength ranging from 350 nm to 500 nm in this the spectrum based study [7]. As shown in Fig. 2 the Sensor LED of 440 nm is connected in series with current limiting resistance. The Sensor LED is connected to the controller by name Sensor_LED on 7th pin of PORTC of controller unit.

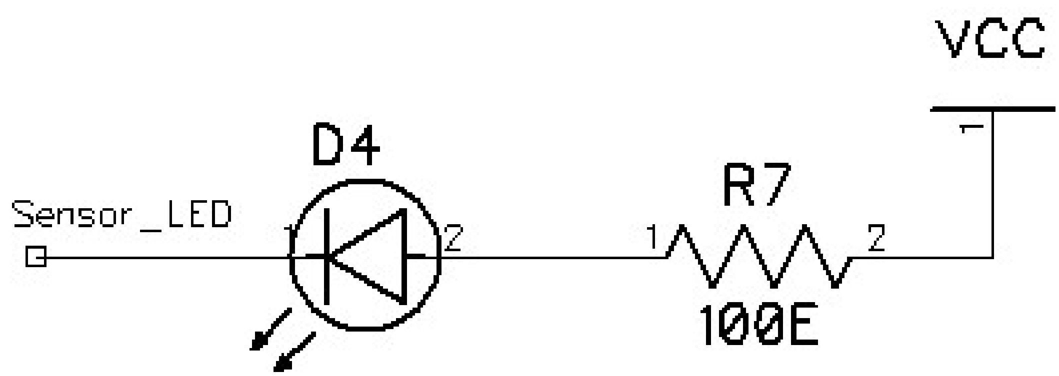

Fig. 2. Light source

2.2.1.2 Sensor

The intensity of the transmitted light is measured at other end by the optical sensor. The change in light intensity as sensed by the sensor gives the absorbance of light. Fig. 3 shows the connection details of colour sensor. Input of colour sensor is connected through microcontroller. The COLOR_SENS_XXpins from controller is connected to colour sensor to control the sensor output. This sensor gives frequency output according to the intensity of sensed colour incident upon it.

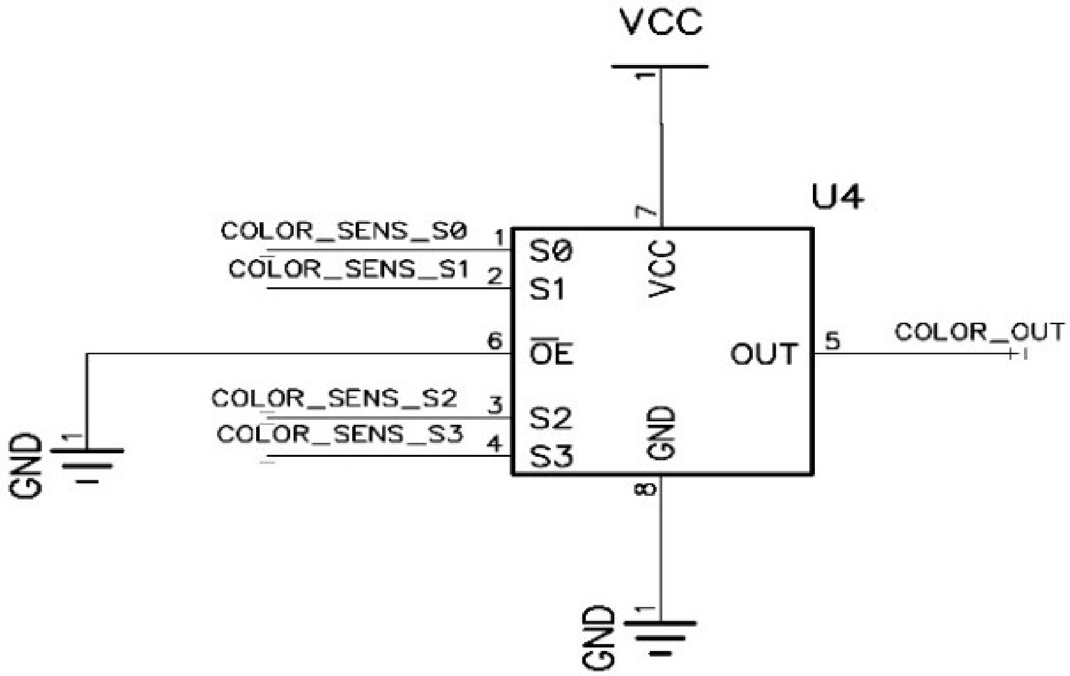

Fig. 3. Colour sensor

2.2.2 Instrumentation system

This is designed by employing the TCS3200, the light to frequency converter [12]. It consists of an 8x8 array of photo diodes. Among these, 16 photodiodes have blue filters, 16 photodiodes have red filters, 16 photodiodes have green filters and 16 photodiodes are clear with no filters. These four types of photodiodes are integrated to minimize the effect of non-uniformity of incident irradiance. All photodiodes of the same colour are connected in parallel. Pins S2 and S3 are used to select which group of photodiodes (red, green, blue, clear) are active. Photodiodes are 110 μm x 110 μm in size and are on 134 μm centres. Output-frequency scaling is controlled by two logic inputs, S0 and S1. The internal light-to-frequency converter generates a fixed-pulse width pulse train. Scaling is accomplished by internally connecting the pulse-train output of the converter to a series of frequency dividers. The division of the output frequency is accomplished by counting the pulses of the principal internal frequency. The final-output period represents an average of the multiple periods of the principle frequency. The frequency can be read on controller by using its external interrupt feature. The sensor is kept in always enable position by grounding its enable pin. COLOR_OUT pin as shown in Fig. 3 is connected to the second pin of PORTD of microcontroller.

2.2.3 Control system

The BODMAS circuit has been designed by employing the microcontroller at mega 16 [8] as shown in Fig. 4. This circuit contains crystal clock circuit to drive the controller, reset circuit to restart the controller and control switches to control the operations. These are the basic components to run this microcontroller based application.

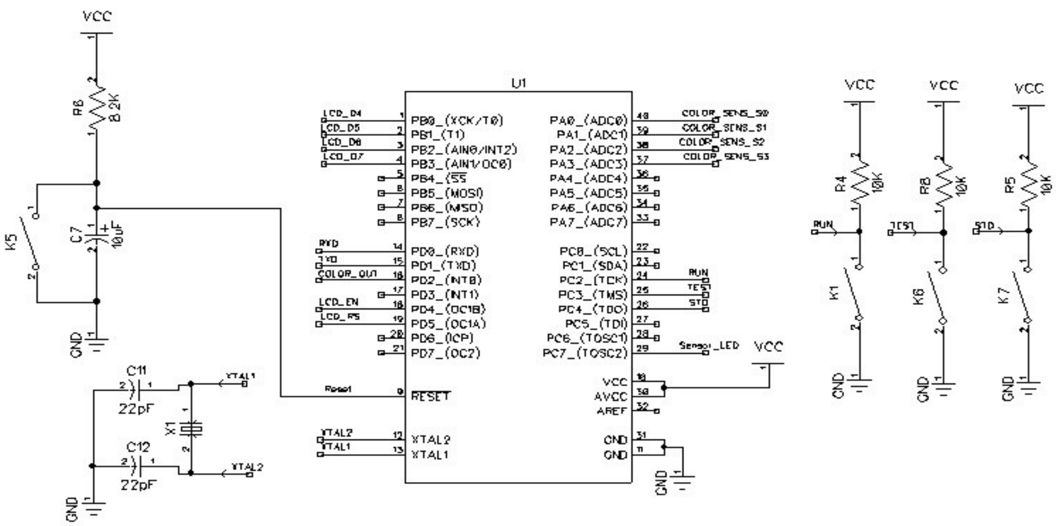

Fig. 4. Controller circuit

Reset switch (K5) is connected with reset pin of controller. Crystal (X2) is connected to controller by XTAL pins. The operation of BODMAS is controlled by three push switches connected in the circuit. They are used to perform many operations i.e. start the test, take the reading, take data on computer, entering in standard mode and etc. These push switches are connected to 2nd, 3rd and 4th pin of PORTC of controller and operate as follows:-

a) 'STD' push switch is used to enter the standard mode of operation. In standard mode, the system acquires the readings of samples or standard solutions. They can be transferred to computer by pressing TEST push switch. These readings are used to calculate slope (m) and constant (c) for converting the frequency value to DO value by use of linear curve based mathematical model. The calculated values of m and c are uploaded through computer. After uploading the readings the instrument returns back to its normal state. Once the instrument is put in standard mode, it will wait until the instrument receives value from computer otherwise it continues to remain in standard mode. In order to take latest test results on computer 'STD' and 'TEST' push buttons are pressed together.
b) 'RUN' push switch is used to start a 5 days BOD test for any sample. In circumstances that require the stopping and restarting of test schedule, this RUN switch is pressed for five seconds to reset the test.
c) 'TEST' push switch is used to update the reading of a test. In a period of five days, presently the system is designed to take maximum five readings per day. Thus the system is restricted to take a set of maximum 25 readings of any BOD test.

2.2.4 Power supply

Supply points (VCC & Ground) are connected to power the controller with 5 V D.C. supply, as shown in Fig. 5. This supply is drawn from the regulator IC 7805 which provides 5 V D. C. regulated power supply when fed from a 9 V rechargeable battery. This makes the device portable. The battery can be recharged through the battery charger circuit while working in the laboratory. Under this condition the circuit will also be supplied from the A.C. mains. The circuit has been protected against overcharging and deep discharging of battery by using relays. 230 V A.C. is applied to the circuit where step down transformer with bridge rectifier and filter circuit convert it into 9 V for charging the battery and giving supply to the regulator IC.

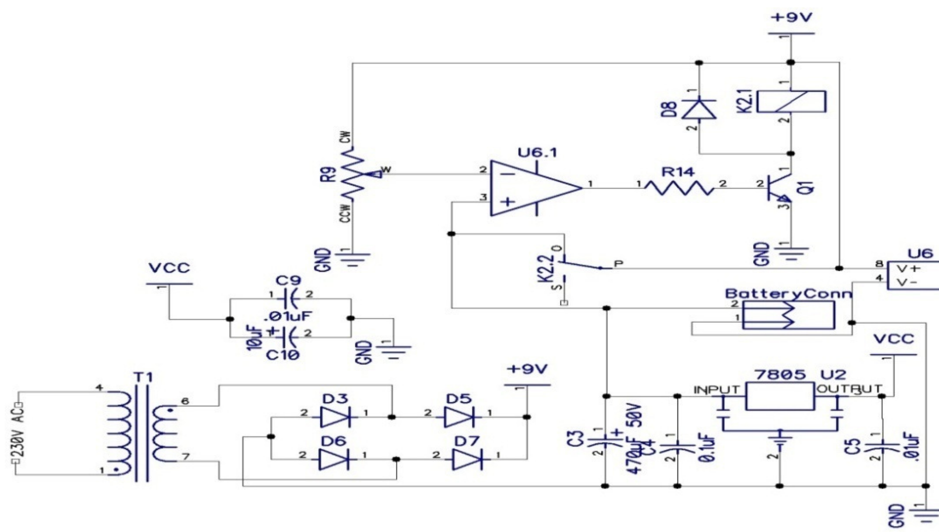

Fig. 5. Regulated power supply and filter circuit

2.2.5 Display

Fig. 6 shows the circuit of LCD display [11] that is connected to controller circuit. The six pins named LCD_XX are controlled by lines of PORTB & PORTD of controller as shown in Fig. 4. An internal potentiometer is employed to set the brightness of the LCD during the design process and can be used by the operating or service personnel to adjust the brightness or contrast. This option is not available to end user or customer.

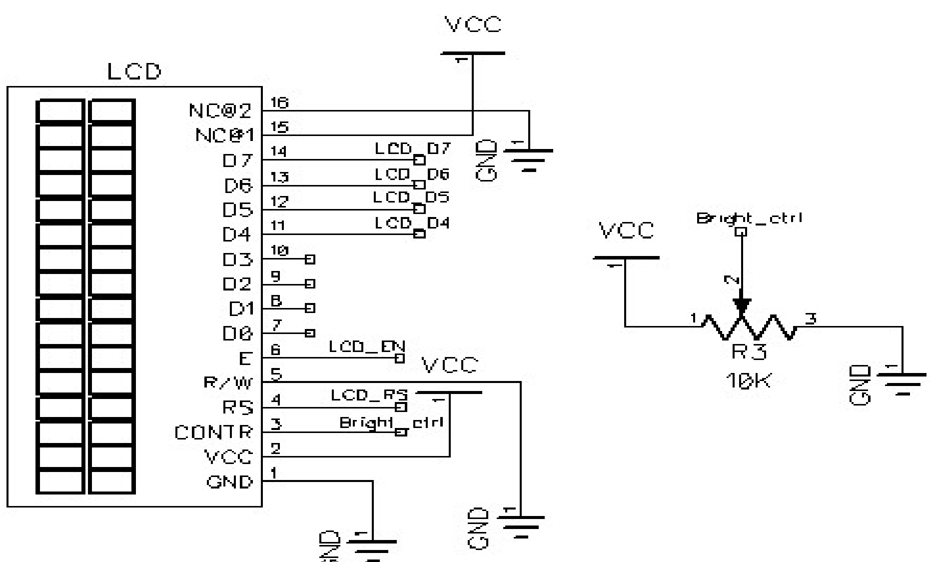

Fig. 6. LCD circuit

2.2.6 Serial communication system

Fig. 7 shows the circuit for serial communication [9]. The USB connector (J1) is used to interface the instrument with the computer. This device is employed to upload data to the computer and is driven by the controller. RXD and TXD pins connected to TXD and RXD pins of controller, respectively.

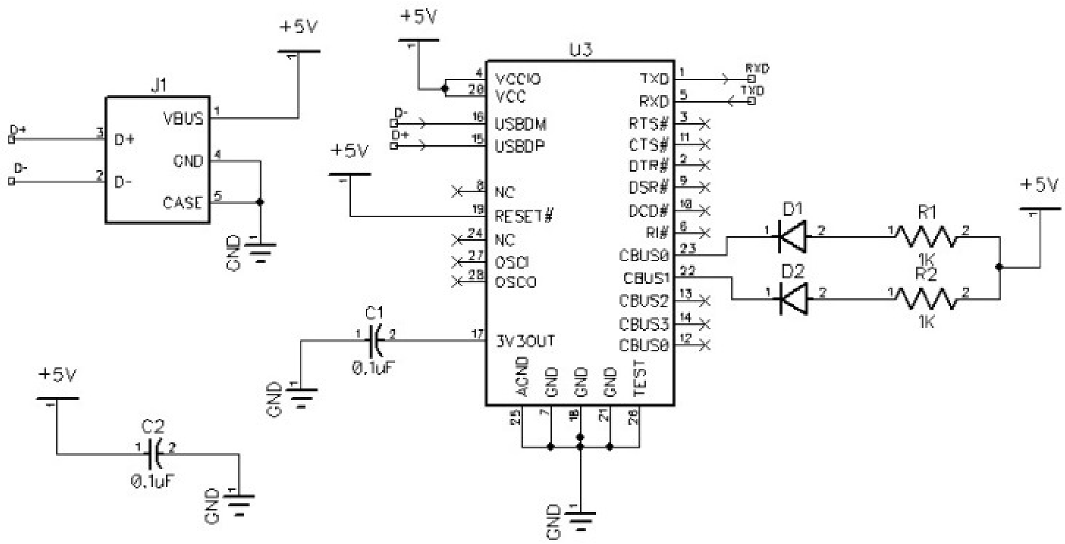

Fig. 7. Serial communication circuit

2.3 Circuit Layout

The complete circuit that includes all the sub-systems described in section 2.2 is shown in Fig. 8.

2.4 Functioning of BODMAS

The readings of BODMAS show the amount of light received on the transducer side, after it passes through the solution in the test tube held in the testing vice. Thus the difference of light emitted by the source and that received on the transducer side indicates the amount of light absorbed by the sample and the associated equipment such as test tube, vice etc. In order to assess the amount of light absorbed by solution, it is hence necessary to implement blank (dilution water) correction so as to account for the drop in absorbance of solution due to light absorbed by the associated equipment and dilution water. For this purpose, the first observation is taken by putting the blank solution along with necessary reagents in the testing vice and the subsequent readings are taken by using different concentrations of the solutions, as per requirement. For BOD determination, absorbance values pertaining to dissolved oxygen on the 1^{st} day and that after incubation of solution for 5 days are measured. Due care was exercised to ensure that the sample bottles are sealed properly on the first day so that no atmospheric oxygen gets dissolved into the solution during the five day incubation process.

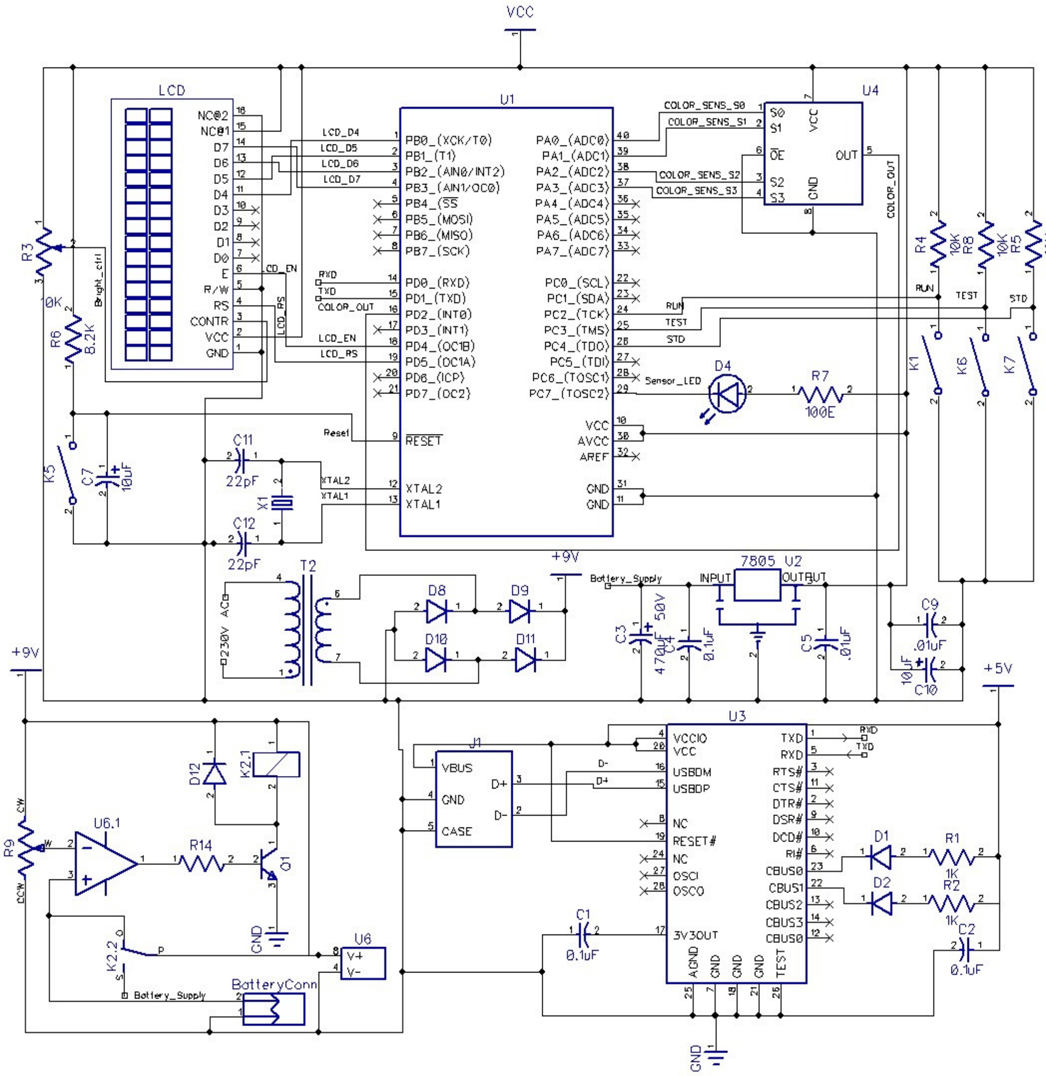

Fig. 8. Design and circuit layout of BODMAS

2.5 Software Development

The algorithm for functioning of BODMAS includes the following major steps:

Step – 1:- Switch ON the power of the instrument to initialize the serial communication port and timer.

Step – 2:- Check whether RUN or STD switches are pressed.

Step – 3:- When the STD switch is pressed, BODMAS goes into standard data collection mode. The absorbance value for the standard solution can be collected by placing the test tube containing the standard solution in the testing vice and pressing TEST switch to send the standard solution absorbance data to PC. The linear coefficients m and c are calculated and returned back to BODMAS. After collecting the m and c values from serial port go to Step – 2.

Step – 4:- If RUN switch is pressed, BODMAS starts the five day test and takes the first reading of test automatically and stores it in the inbuilt memory of controller. The reading of BODMAS shows the number of gate pulses passing through a fixed aperture time of 500 ms, passing through the instrumentation system, and frequency of these pulses is proportionate to the intensity of light received by the sensor. A convenient measure of comparison and indication was developed by dividing the number of pulses by 500, to obtain the number of pulse per millisecond.

Step – 5:- BODMAS now remains in wait state until the next switch is pressed. A countdown of five days is started and continues in background.

Step – 6:- For taking a runtime DO reading, press the TEST switch to measure absorbance and convert it to DO using the m and c values.

Step – 7:- Save the DO results in the inbuilt memory of controller and return to Step - 5.

Step – 8:- For taking the DO results, stored in the inbuilt memory of controller, BODMAS is connected to the PC through USB cable. Press both the TEST and RUN switch simultaneously to transfer the data to PC.

Step – 9:- After uploading the data on the PC, BODMAS return to Step – 5.

Step – 10:- To reset the running test process press RUN switch for 5 seconds. If the switch is released before the elapse of 5 s, BODMAS will continue to remain in Step – 5.

Step – 11:- To reset the test and to enter the new standard readings press STD switch. The system now goes to special wait state for 5 s. If STD switch is again pressed in this wait state the system will reset and return to Step-3. But if special state passes away the system will return to Step – 5.

Step – 12:- After the 5 day period is completed the system returns to Step – 2.

Step – 13:- The result saved in memory can be collected from BODMAS till the new test cycle is initiated.

The flowchart given as Fig. 9 presents a pictorial view of the algorithm described above.

3. CALIBRATION AND TESTING

The calibration of BODMAS was carried out by using potassium dichromate solution and its testing was done by using the standard GGA solution as described in the following sections [7].

3.1 Calibration

The designed instrument is expected to be responsive to the shades of yellow colour, as shown by changing level of DO in the prepared solution after the addition of reagents. The calibration of BODMAS was done by employing standard potassium dichromate solution in the concentration range 0.3 ppm to 1.5 ppm. The absorbance readings obtained from commercial spectrophotometer (model DR5000, HACH, USA) was used for the comparison of performance of BODMAS. The calibration characteristics are shown in Fig. 10. It was found that the response of BODMAS is fairly linear and is similar to the response obtained from the spectrophotometer for the selected concentration range. The correlation matrix was evaluated and its elements were close to unity indicating good correlation.

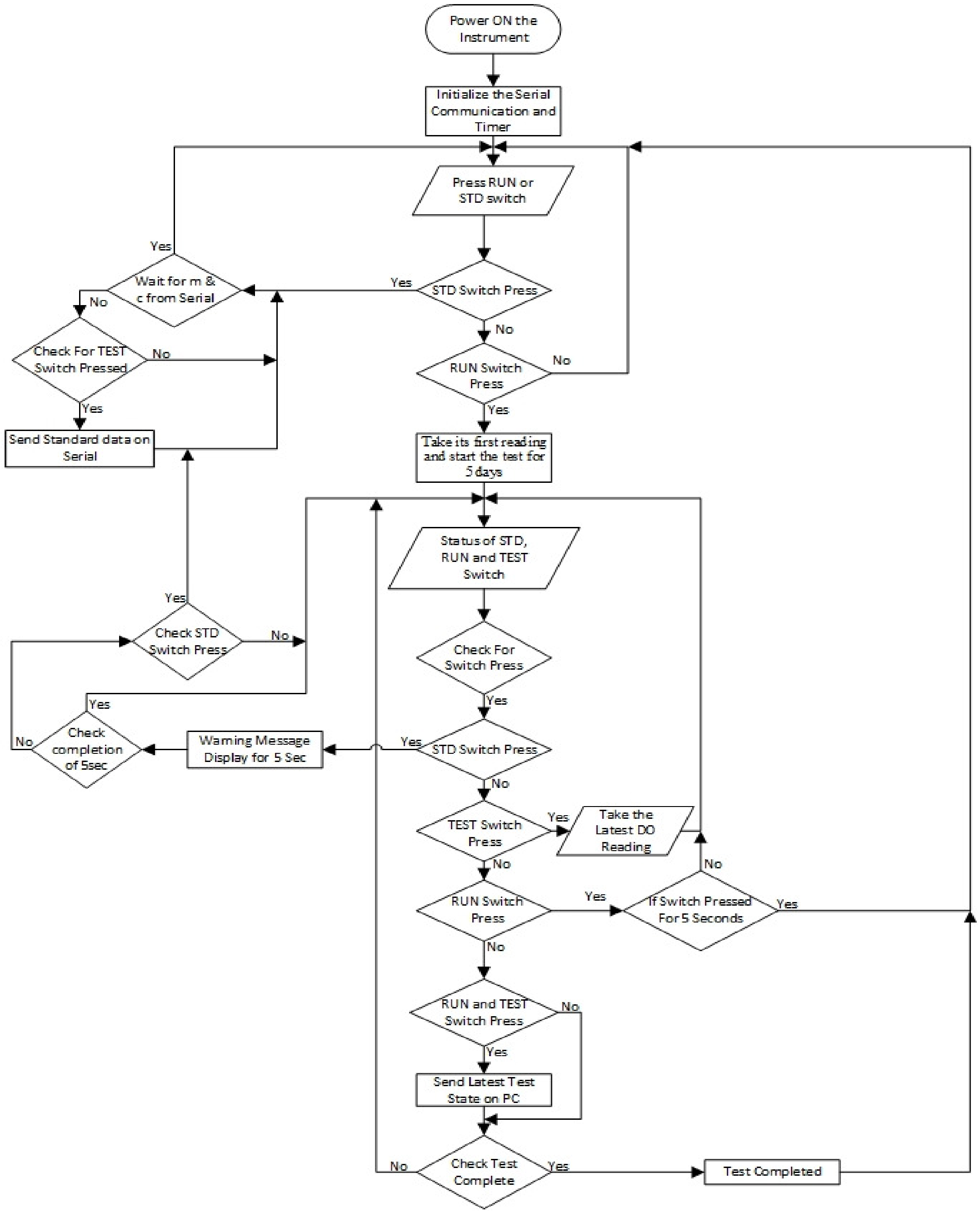

Fig. 9. Flowchart of Software of BODMAS

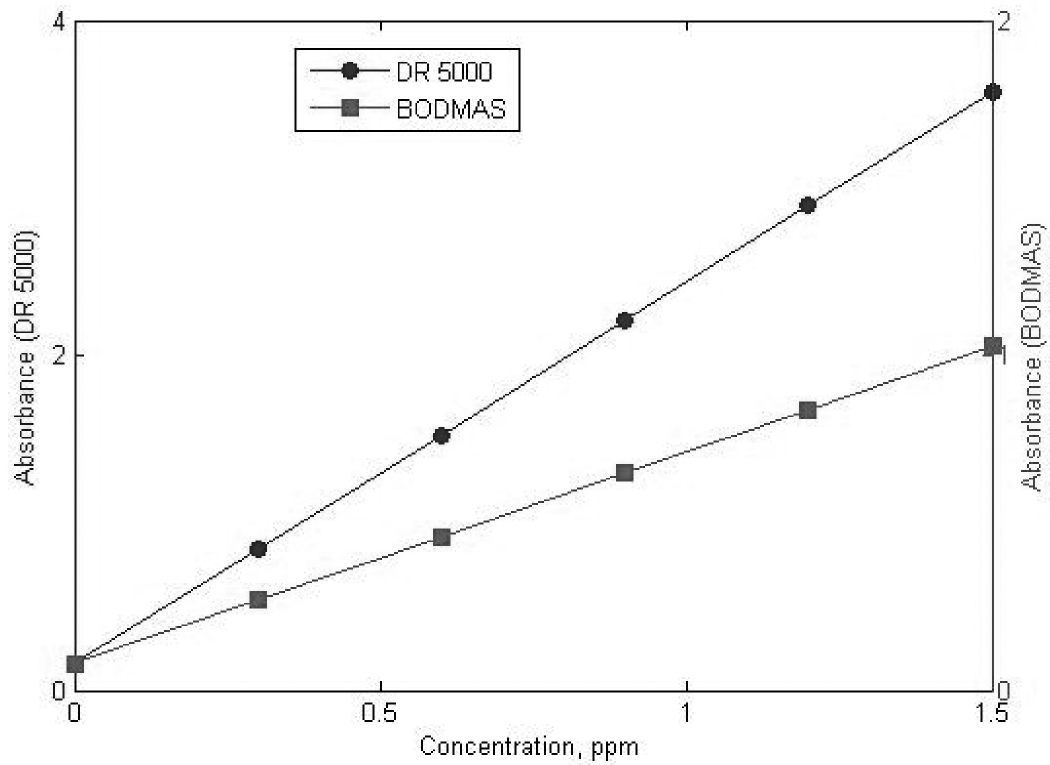

Fig. 10. Calibration characteristic

3.2 Performance Testing

This process of testing was carried out to validate the performance of the designed instrumentation system. The calibrated instrument was applied for the measurement of BOD for standard GGA solution. Experimentation was carried out to obtain the relation between the absorbance of 440 nm monochromatic light and the amount of dissolved oxygen. The oxygen consumed on day 1 (DO_1) and that after incubation for 5 days (DO_5) were measured. The ten different dilutions of GGA were prepared and tested. DO reading from the Winkler's titrimetric method and absorbance by BODMAS were recorded for Day1 and Day5 following the method reported from our laboratory [7]. The Winkler's DO (B_1 and B_5) and the absorbance readings (AB_1 and AB_5) for blank solutions i.e. 0% concentration, served as reference for both the days. A mathematical model [7] based on Pearson's correlation coefficient was derived by using the MATLAB ® Software 2012a in order to convert the absorbance values to DO values. The readings and intermediate calculations are depicted in Table 1. The estimated values of difference of DO for Day1 and Day5 obtained from the model depicted a reasonably good similarity with the corresponding values obtained from Winkler's method.

The final relationship between the blank corrected difference of absorbance and that of DO values for Day1 and Day 5 obtained is given by eq. 1

$$DO_1' - DO_5' = 7.4404x + 0.7942 \quad (1)$$

This equation can be used for obtaining the difference of DO values for Day1 and Day 5 for any concentration, after substituting the corresponding values of difference of absorbance, x from the observation obtained by BODMAS. Now, the BOD for the sample is calculated from the difference of DO values by using eq. 2.

$$\mathrm{BOD} = \frac{\left[\left(\mathrm{DO_1}' - \mathrm{DO_5}'\right) \mathrm{X}\ 100\right]}{\mathrm{c}} \tag{2}$$

Where

DO_1'- DO_5'= difference of DO depletion in five days
c = % sample / GGA concentration

The values of BOD obtained by BODMAS as depicted in Fig. 11 show close agreement with those obtained by Winkler's titrimetric method, which is considered to be the standard reference method for BOD determination. The correlation coefficients are calculated and are found to be close to 1, thus indicating good correlation. This validates the performance of the designed instrumentation system.

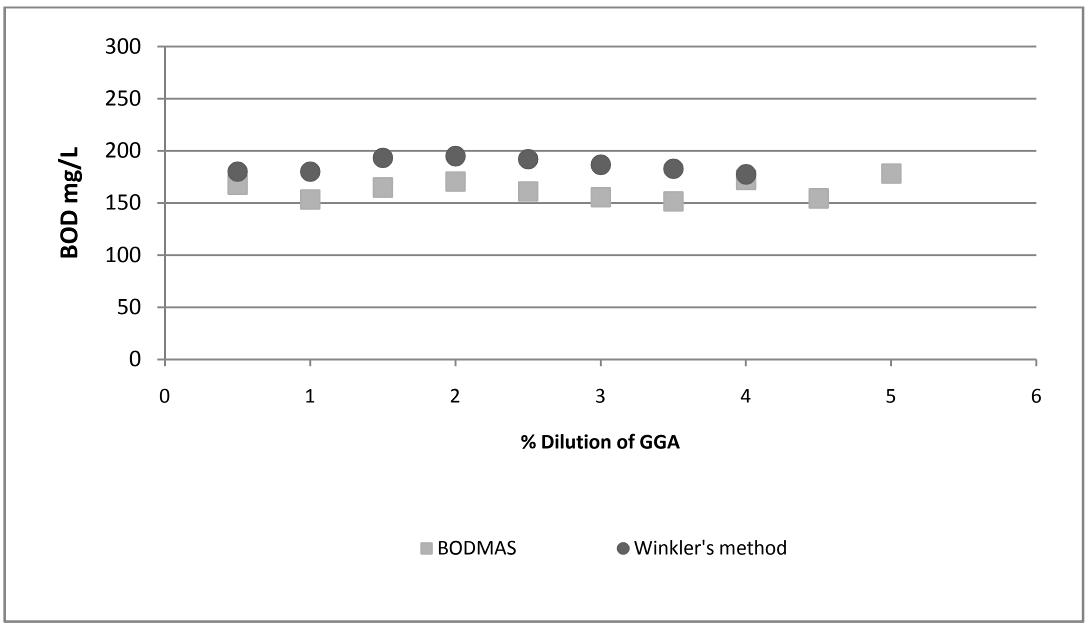

Fig. 11. BOD of GGA at different dilutions

Table 1. Comparison of DO values obtained from Winkler's method and absorbance based instrumental method

Sample (150 ppm GGA)		**Winkler's DO, mg/L**			**Absorbance**			**(DO_1'DO_5') as modelled**
Blank	**0**	**B_1 = 8.1**	**B_5 = 8.0**	**$B_1 - B_5$ = 0.1**	**AB_1 = 0.127**	**AB_5=0.135**	**AB_1-AB_5=0.008**	
ppm	**% conc**	**DO_1**	**DO_5**	**$Y=(DO_1-DO_5)-(B_1-B_5)$**	**A_1**	**A_5**	**$X=\|(A_1-A_5)-(AB_1- AB_5)\|$**	
0.75	0.5	7.8	6.8	0.9	0.180	0.292	0.112	0.837
1.50	1.0	7.8	5.9	1.8	0.216	0.424	0.207	1.543
2.25	1.5	8.3	5.3	2.9	0.171	0.504	0.332	2.474
3.00	2.0	8.0	4.0	3.9	0.220	0.678	0.459	3.413
3.75	2.5	7.6	2.7	4.8	0.201	0.742	0.541	4.027
4.50	3.0	7.9	2.2	5.6	0.260	0.887	0.627	4.669
5.25	3.5	8.5	2.0	6.4	0.249	0.962	0.712	5.301
6.00	4.0	8.2	1.0	7.1	0.206	1.132	0.926	6.891
6.75	4.5	8.3	0.8	7.4	0.194	1.129	0.934	6.952
7.5	5.0	8.4	0.4	7.9	0.158	1.356	1.198	8.915

4. CONCLUSION AND FUTURE SCOPE

This paper presents the development, calibration and testing of BODMAS, a portable device developed for optometric measurement of BOD by the measurement of difference of absorbance on day1 and after incubation for 5 days. The design, working and methodology of use of equipment have been discussed in detail. The calibration of BODMAS to assess its performance was carried out by using potassium dichromate solution which develops yellow colour in a manner similar to that developed by the samples after addition of Winkler's reagents to it. The functioning of the equipment has been illustrated by conducting experiments for BOD measurement for different dilutions of GGA; the results were in good agreement with those obtained by Winkler's method. The operation of developed microcontroller based optical transducer device is quite simple and it is easy to use for non-experts. The developed portable BOD instrument is light weight, battery operable and compact for facilitating field use for the quality assessment of waste waters, effluents, sewage treatment.

ETHICAL APPROVAL

Not applicable.

COMPETING INTERESTS

Authors declare that there are no competing interests.

REFERENCES

1. Rice EW, Baird RB, Eaton AD, Clesceri LS. Standard methods for the examination of water and wastewater. 22nd ed. APHA, AWWA, WEF; 2012.
2. Dobbs RA, Wise RH, Dean RB. The use of UV absorption measurement of monitoring the total organic carbon content of water and wastewater. Water Research. 1972;6:1173-1180.
3. Markva M. Automatic UV control system for relative evaluation of organic water pollution. Water Research. 1975;9:587-589.
4. Markva M. Evaluation of correlation between absorbance at 254 nm and the COD of river water. Water Research. 1983;17:231-235.
5. Bari A, Farooq S. Measurement of wastewater treatment efficiency by fluorescence and UV absorbance. Environmental Monitoring and Assessment. 1985;5:423-434.
6. Reynolds DM, Ahmad SR. Rapid and direct determination of wastewater BOD values using a fluorescence technique. Water Research. 1997;31(8):2012-2018.
7. Singh U, Sharma V, Bhandari S, Vajpai J, Kumbhat S. Absorbance based model for determination of Biochemical Oxygen Demand. British Journal of Applied Science and Technology. 2014;4:4409-4420.
8. Datasheet of Microcontroller ATMega16. 8-bit Microcontroller with 16K Bytes In-System Programmable Flash. Accessed 2 November 2012. Available: http://www.atmel.in/Images/doc2466.pdf.
9. Datasheet of FT232RL. Future Technology Devices International Ltd. FT232R USB UART IC. Accessed 12 February 2013. Available:http://www.ftdichip.com/Support/Documents/DataSheets/ICs/DS_FT232R.pdf.

10. Datasheet of 20x4 LCD Display. Accessed 2 November 2012. Available: http://www.systronix.com/access/Systronix_20x4_lcd_brief_data.pdf.
11. Datasheet of 440 nm LED. Accessed 12 July 2013. Available:http://www.ebay.com/itm/5-pcs-Blue-Color-Light-High-Power-LED-Lamp-1-Watt-440nm-/230768818912.
12. Datasheet of Instrumentation system and sensor. TCS3200, TCS3210 Programmable Color Light-to-Frequency Converter. Accessed 21 December 2012. Available: http://www.dfrobot.com/image/data/SEN0101/TCS3200%20TCS3210.pdf.

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