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MULTI SENSOR SYSTEM FOR MONITORING OF WATER QUALITY

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Abstract

Water quality monitoring system was designed and developed by using pH, Oxidation Reduction Potential (ORP) and temperature sensors for swimming pool. The output of the system was displayed on the LCD display and the measurement data was recorded into SD Card. The developed system was compared to the commercial pH and chlorine meter to verify the accuracy and the functionality of the system. The system was, then, used to measure the water quality level from the water of UPM swimming pool. The levels of all these parameters were found to be under the UPM Swimming Pool Working Manual for Water Quality Testing as well as the acceptable standard values set by the World Health Organization for swimming pool water. These results indicate that the water of the swimming pool of the proposed study is still in good conditions and good quality, suitable for recreational activity inside the swimming pool and not hazardous to human life.

Keywords: Monitoring system, Oxidation-reduction potential, pH, Temperature.

1. Introduction

Swimming pool is an artificially created structure filled with water used for swimming and water-based recreational activities. The condition of a swimming pool greatly depends on how well the chemical properties is monitored and corrected. Swimming pool chemistry can be quite complex and many chemical tests need to be performed on a regular basis to maintain the swimming pool in a good condition [1]. For best practice, pH and chlorine levels need to be checked daily and preferably, these tests should be done before the first swim of the day to make sure the water quality has not been altered overnight. In the proposed design, the critical parameters of the water quality that will be observed are pH, temperature and chlorine.

Chemical values must be right for disinfection, safe for swimming and good for pool materials [2]. Chlorination is one of many methods that can be used to disinfect water. The amount of each compound present in the water is dependent on the pH level of the water prior to addition of chlorine [3]. The level of disinfection is determined by the pH and temperature of the water. At lower temperature with a higher pH level, the disinfection level will have to be increased, and a higher water temperature with a lower pH level will also allow for a lower disinfection level. However, this relationship is also controlled by the composition of the water. The more micro organisms contained in the water, the lower the level of the disinfection. Thus, it can be decided that these three parameters, which are pH, temperature and chlorine, is the most important matter to be monitored to ensure the water quality of the swimming pool at its optimum state.

The conventional swimming pool water quality monitoring system used by the pool operators usually includes several steps need to be taken while checking the water condition such as ensuring the right tablets for each parameter measurement, adding right solution to enhance the water quality, taking the sample of swimming pool water from every pool corners and many more steps. Hence, by creating the alert system, which is displaying the water quality measurement and condition, the corrective action could be taken in shorter time and less energy required during the inspection time. Besides that, the monitoring task can be performed only when necessary such as when the maintenance of the swimming pool in order to analyze the behaviour of the swimming pool water.

The main goal of this project is to develop a monitoring swimming pool water quality using multi sensor and to alarm the pool management about the water condition. By doing so, the water contamination in the swimming pool can be monitored to ensure the safety and health of the swimmers.

2. Methodology

The process of designing and developing the swimming pool water quality monitoring system using multi sensor involves a few important steps, as outlined in the flow chart in Fig. 1. The design of the system can be divided into two major parts, which are hardware design and software design. For software part, the circuit for the system is designed. The microcontroller is programmed using Arduino IDE software. For the hardware part, there are three sensors used to develop the swimming pool water quality system, which are pH sensor, temperature sensor and ORP sensor. The calibration of the pH, temperature and ORP sensors was done before these sensors were assembled into the designed system.

Finally, after the functionality and accuracy of developed system was verified, the system was installed into the casing so that it can be used as a portable device.

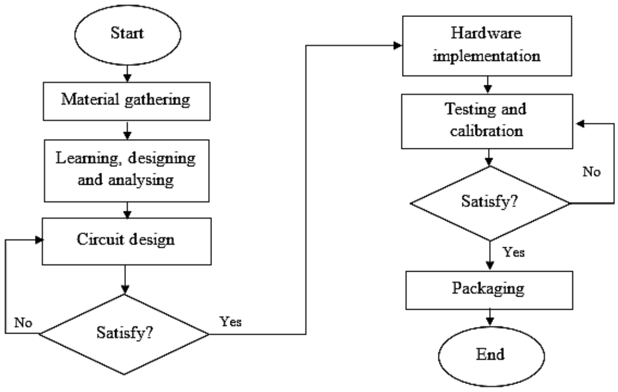

Fig. 1. Design flow of swimming pool water quality system.

2.1. Software design

The software used to program the Arduino Uno board is Arduino Software (IDE). The language used to program the board is a simplified C language.

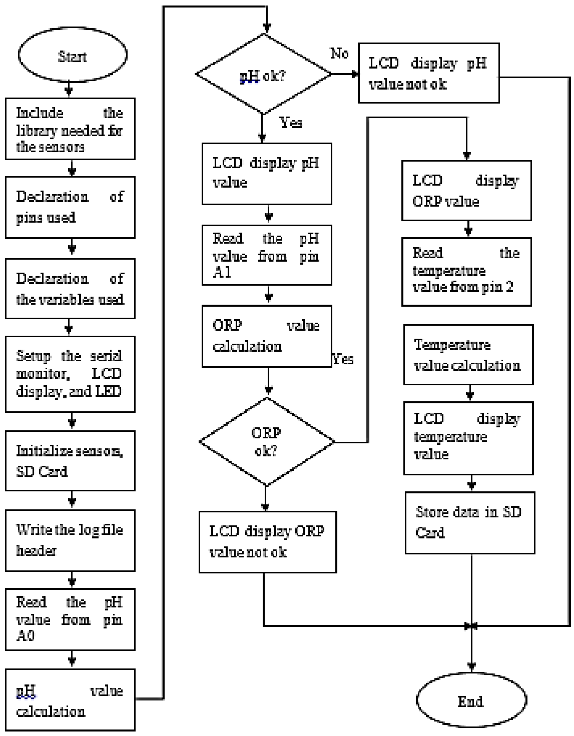

Fig. 2. Flow chart of the program written for the developed system.

Figure 2 shows the flow chart of the program written for the swimming pool monitoring system. First of all, the program started with including the header file or the library, and declaring the pins and variables used in the program such as voltages, the pH, temperature and ORP values. The setup was done to the serial monitor so that the output of program executed could be seen from the serial monitor of the software. The LCD was setup for the output display in the next program execution. The on-board LED was also setup for the use of the clock timing. Apart from that, the sensors, which were pH temperature, and ORP sensors as well as SD card were initialized. As the data logger was created for this program, the output file was started with a header to ease the data storing and interpreting.

The formula used for pH value calculation is:

$$voltage = \frac{averagearray(pHArray, ArrayLength) \times 5.0}{1024} \quad (1)$$

$$pHValue = 3.5 \times (voltage + Offset) \quad (2)$$

where voltage = the voltage of pH [mV], averagearray = the average of pH value read from pH sensor, pHValue = value of Ph and Offset = offset voltage from the actual reading [mV].

Equation (1) is used to convert the analogue reading of the pH sensor into digital, which is done by the 10 bit ADC range conversion. Eq. (2) is used to calculate the pH value for the corresponding voltage of the reading.

The formula used for ORP value calculation is:

$$orpValue = ((30 \times voltage \times 1000) - (75 \times averagearray(orpArray, ArrayLenth) \times voltage \times 1000/1024))/75 - Offset \quad (3)$$

where orpValue = value of ORP [mV], voltage = the voltage of operating voltage of the microcontroller[mV], averagearray = the average of pH value read from ORP sensor, and Offset = offset voltage from the actual reading [mV].

Equation (3) gives the calculation of ORP value, where the analogue reading of the ORP sensor is directly converted to the voltage reading according to the circuit.

2.2. Hardware design

2.2.1. Microcontroller

For this project, the Arduino Uno acts as the brain of the monitoring system. Arduino hardware and software is based on open source system, where the designs and software are available to be referred and adapted. Arduino Uno is a microcontroller board based on the ATmega328P. Total pin used is 22 pins out of 28 input/output pins. This microcontroller is selected for the design because of the simplicity of the circuit, the use of its 10 bits ADC saves more space required for the system, and its input/output pins are fully utilized, reprogrammable, and capable to be used for monitoring system development.

2.2.2. I/O Expansion Shield for Arduino

For analogue pins, as the pH sensor and ORP sensor use BNC connectors that come with PH2.0 interface, it requires single analogue pin, power and ground pins to communicate with the sensors, which the I/O expansion shield provides the best solution by using the set of power, ground and data pins on the analogue part. For digital part, the board provide SD Card socket, hence the digital pins used for SD Card are reserved The conflict between the digital components sharing the same pins has been resolve as there are some unused digital pins on the shield that can be assigned to these components. Thus, this board is used to optimize the use of the input and output pins as well as simplify the complexity of the circuit.

2.2.3. pH Sensor

pH sensor measures the hydrogen ions in a solution and provides the output reading in voltage. In a combination pH electrode (refer to Fig. 3), the most widely used type, there are actually two electrodes in one body. One portion is called the measuring electrode, the other the reference electrode. The potential that is generated at the junction site of the measuring portion is due to the free hydrogen ions present in solution. The potential of the reference portion is produced by the internal element in contact with the reference fill solution. This potential is always constant. In summary the measuring electrode delivers a varying voltage and the reference electrode delivers a constant voltage to the meter [4].

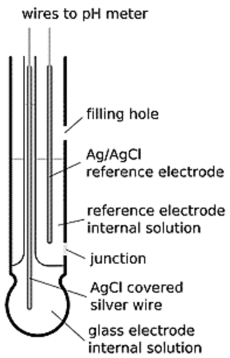

Fig. 3. Typical combination electrode construction for pH sensor [5].

2.2.4. OPR Sensor

Similar to pH sensor, this ORP sensor is also an analogue ORP meter, specially designed for Arduino controllers and has built-in simple, convenient and practical connection and features. ORP (Oxidation-Reduction Potential) is a measure of the ability of oxidation and reduction of aqueous solution, characterization of the relative degree of oxidizing or reducing in mV. Oxidation reduction potential is high when the oxidation is stronger, while the potential is lower when the oxidation is weaker. The positive potential means that solution shows a certain degree of oxidation, while the negative potential means that solution shows a certain degree of reduction.

2.2.5. Temperature Sensor

The temperature sensor used in this project is a waterproof digital temperature sensor DS18B20. The sensor consists of four parts which are a 64-bit ROM, temperature sensor, the temperature of non-volatile alarm triggers (TH and TL), and configuration register. The core functionality of the DS18B20 is its direct-to-digital temperature sensor. The resolution of the temperature sensor is used in this project is 10 bits which gives out the output reading in two decimal places value. The sensor is capable of measuring temperature ranging from –55°C to +125°C.

2.2.6. Data Logger

The data of the measurement made by the system is stored in a data logger, which is a SD card for this project. To install the SD card to the system, a SD card breakout board (Fig. 4) is mounted to the I/O Expansion Board by connecting it to the SD Card socket of the board. The data saved in the SD card can be retrieved and analyzed using a spreadsheet-based software such as Microsoft Excel.

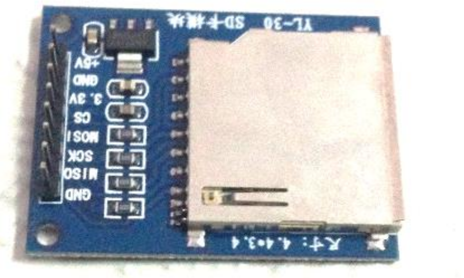

Fig. 4. SD card breakout board.

2.2.7. Overall Circuit Design

With refer to Fig. 5, swimming pool water quality system was designed by using Atmega328 microcontroller, three sensors which were pH, ORP and temperature sensors, as well as LCD display and SD Card socket. Tblock J1 was for temperature sensor connection, whereas Tblock J2 was for SD card breakout board connection. Meanwhile, Tblock J3 was for pH sensor connection and lastly, Tblock J4 was for ORP sensor connection. The use of Tblocks in the circuit design was to ease the connection of the circuit between the I/O Expansion Shield for Arduino and the components on the breadboard. The connection to LCD display was also shown in Fig. 5.

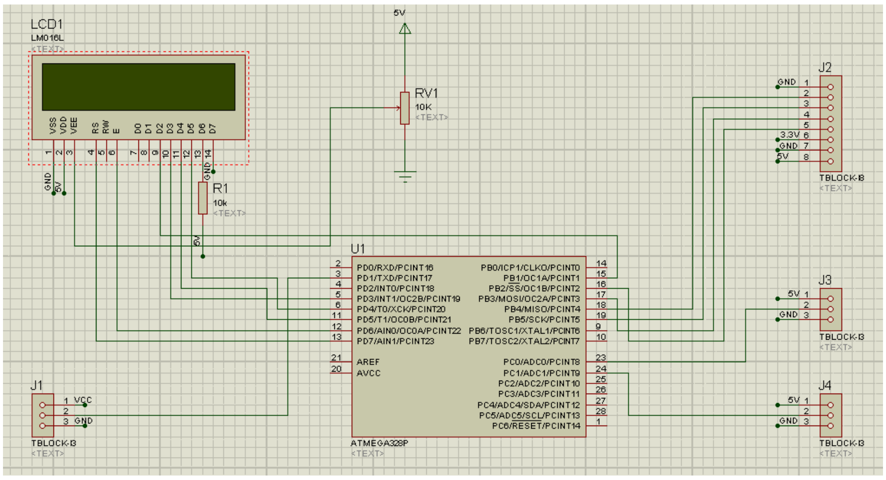

Fig. 5. The circuit design of the swimming pool water quality monitoring system.

3. Results and Discussion

The results obtained from both comparing the developed system with commercial meters and testing the developed system by using UPM swimming pool water.

3.1. Comparison between the developed system and commercial pH system

Once the casing of the developed swimming pool water quality monitoring system was done, the developed system was tested using the swimming pool water for several times in order to verify the functionality of the system. In addition, the reading made by the developed system also been compared to the reading when using the Scuba Pool Tester kit. The comparison was performed to confirm the precision of the system and the accuracy of the pH measurement from the developed system as compared to the commercial pH meter. The results obtained were shown in plot, as shown in Fig. 6, of the comparison between the developed systems with the commercial meters.

By referring to Fig. 6, the deviation of the measured pH values in between the developed system and commercial pH meter which is Scuba Pool Tester Kit was acceptable since the largest deviation was only 0.03 or 0.4% for the pH value of the swimming pool water. The pH sensor used in the project has an accuracy tolerance of ±0.1pH while the commercial pH meter has an accuracy tolerance of ±0.2pH. The reading of the pH sensor in the developed system can be taken in multiple times whereas the reading measured by the commercial pH meter was taken once and assumed constant for the next few readings. Thus, the deviation value was actually showing how far the commercial pH meter measurement deviates from the real time measurement made by the pH sensor of the developed design.

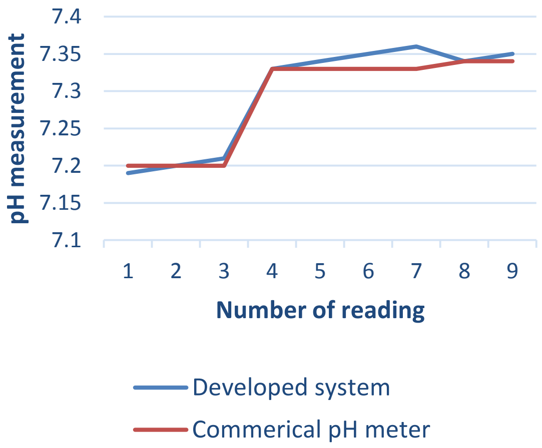

Fig. 6. The plot of the measured and deviation of pH values between developed system and Scuba Pool Tester Kit.

3.2. Comparison between the developed system and commercial chlorine system

The developed swimming pool water quality monitoring system was also been compared with the commercial chlorine meter of the Scuba Pool Tester kit. The comparison was done in order to verify the operation and the functionality of the ORP measurement of the developed system as compared to the commercial chlorine meter. Even though the ORP value cannot be compared directly with the chlorine meter measurement, however these two values were much related to each other. The ORP value indicates the free available chlorine inside the water. The ORP and chlorine measurement was taken from the swimming pool water. The result obtained from the measurement was shown in Table 1.

Table 1. The result obtained from chlorine measurement of the commercial chlorine meter and ORP measurement from the developed system.

Chlorine meter		Developed system
Total Chlorine (mg/cl_2)	Free Chlorine (mg/cl_2)	ORP value (mV)
0.35	0.18	662.11

The optimum value for both total chlorine and free chlorine is in the range of 0 to 6.0 mg/cl_2. If the value obtained is in the range, it shows that the chlorine is still available in the swimming pool water. Positive ORP value demonstrates that the chemical reaction occurs in the water is oxidation whereas negative ORP value indicates reduction process of the chemical reaction. During the oxidation process, the chlorine is working greatly as disinfectant. The optimum value for ORP measurement is between 680 mV to 72 0 mV. The value will decrease as the chlorine been used as disinfectant. The result obtained in Table 1 shows both values were correlated to each other, thus the functionality of the developed system was verified.

3.3. The application of the monitoring system during the day

As the swimming pool water quality monitoring system was completely developed and functioning accordingly, this device had been tested throughout the day inside the swimming pool water to see the performance of the water quality parameters. Figures 7, 8 and 9 show the data measurement of swimming pool water obtained for morning, noon and evening time respectively. It contains the pH, temperature and ORP measurement of the swimming pool water.

As stated in the UPM Swimming Pool Standard Working Manual for Water Quality Testing, the ideal range of pH level for swimming pool water is from 7.2 to 8.4 and for the ORP level, it must higher than 650 mV for better disinfecting process. The optimum measurement of the swimming pool water quality was obtained during the morning time. This is due to the water treatment given on the previous night and the swimming pool is not utilised yet during that particular time. By referring to Fig. 7, the pH value was constant at 7.35 and the temperature value was also constant at 31.75^{0}C. Meanwhile, the ORP value was increasing during the first minute of time from 630.6 mV to 631.8 mV. This ORP value showed that the chlorine level inside the swimming pool water was at good condition.

On the other hand, the data measurement shows some changes when the data collection was made during the afternoon time. Figure 8 shows that the temperature during afternoon time was in fluctuation between 32^{0}C to 32.06^{0}C. The ORP value also increased gradually from 507.2 mV to 510.8 mV due to higher temperature value, which is chemical reaction are becoming more active at increased temperature. However, the rapid redox reaction occurred at this time giving result in lower ORP value for the next few hours hence the chlorine level will be decreased. The pH value of the water at this time becoming more alkaline which is 7.72, as shown in Fig. 8.

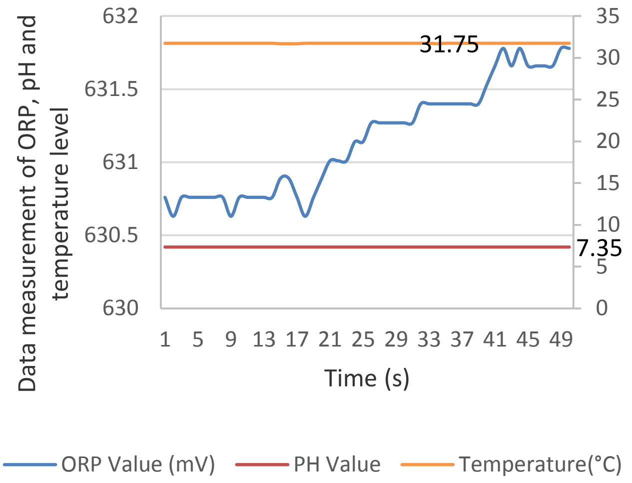

Fig. 7. The plot of data measurement of the ORP value, pH value and temperature value taken at 8.30 a.m.

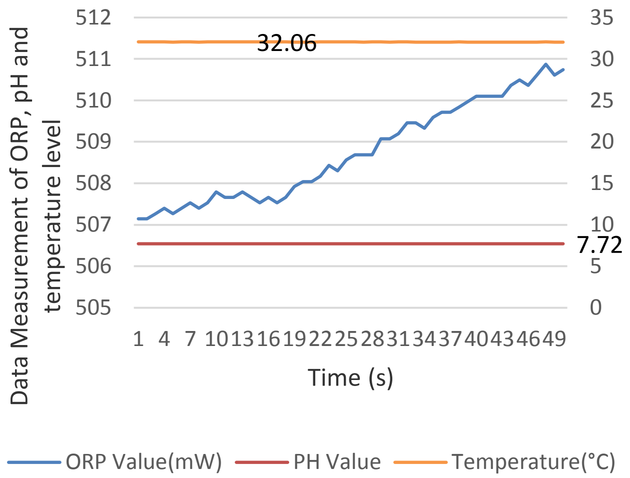

Fig. 8. The plot of data measurement of the ORP value, pH value and temperature value taken at 12.36 p.m.

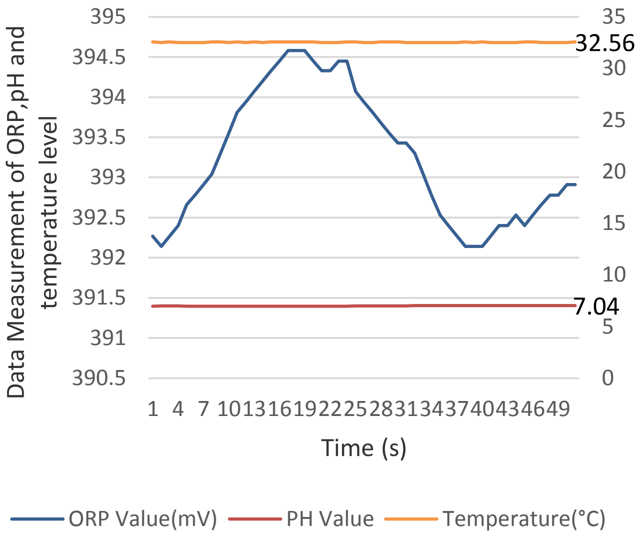

Fig. 9. The plot of data measurement of the ORP value, pH value and temperature value taken at 4.21p.m.

On contrary, as the temperature kept increasing toward the evening time, the pH value decreased correspondingly. This situation satisfies the pH Nernst Equation, which the temperature value is inversely proportional to the pH value. At this time, the temperature value was at 32.56^{0}C and the pH value was 7.04 as shown in Fig. 9. The ORP value became unstable and decrease below the optimum level. Towards the end of the day, the ORP level was getting low showing that the chlorine inside the swimming pool had been reacted with the micro organisms and chemical substances. This environment was no longer suitable for any activity inside the swimming pool.

3.4. Comparison of findings measured by the developed system and manually done by the pool personnel

The data tabulated in Table 2 was obtained for 20 readings in the morning for two consecutive days.

The data taken by the pool personnel was taken once and assumed constant for the next 20 seconds and for the developed system, the system was left in the swimming pool water for 20 seconds to record the pH level of the water. As shown in Table 2, the measurement taken by developed system had varied slightly from the manual system, however, it showed the real time reading of the swimming pool water quality. The developed system is the best solution to keep track of the swimming pool water quality level as it recorded the data in specific interval of time rather than taking the measurement manually for several times.

Table 2. The result of pH level of swimming pool water measures using developed system and manually taken by the pool personnel.

No.	Sample 1		Sample 2	
	Developed system	Manual system	Developed system	Manual system
1	7.16	7.15	7.19	7.2
2	7.16	7.15	7.19	7.2
3	7.16	7.15	7.19	7.2
4	7.15	7.15	7.19	7.2
5	7.15	7.15	7.19	7.2
6	7.15	7.15	7.18	7.2
7	7.15	7.15	7.18	7.2
8	7.15	7.15	7.18	7.2
9	7.15	7.15	7.2	7.2
10	7.15	7.15	7.2	7.2
11	7.15	7.15	7.2	7.2
12	7.15	7.15	7.2	7.2
13	7.15	7.15	7.2	7.2
14	7.15	7.15	7.2	7.2
15	7.15	7.15	7.2	7.2
16	7.15	7.15	7.2	7.2
17	7.15	7.15	7.2	7.2
18	7.14	7.15	7.2	7.2
19	7.14	7.15	7.19	7.2
20	7.15	7.15	7.2	7.2

4. Conclusions

As conclusion, a swimming pool water quality monitoring system that can measure the pH, temperature and ORP values was developed and tested in the project. The system was build using Atmega328 microcontroller as the brain of the system. This project is an improvement for the UPM swimming pool water quality monitoring system as the system can keep the record of the measurements and produce an alert system. For current system, the record is kept manually in the daily report.

The comparison had been made between the developed swimming pool water quality monitoring system and the commercial pH and chlorine meter. The result shows that the measurement obtained was acceptable due to the deviation between the developed system and the commercial meters were not more than 0.03 for pH measurement and 19mW for ORP measurement.

The comparison of the parameters reading taken during three different times of the day was also discussed. The pH reading was highest during the noon, ORP reading was highest in the morning and temperature in the morning was lower than in the noon and evening. On top of that, the effect of the temperature on the pH measurement and the pH influence, pH influence on effectiveness of Chlorine as a disinfectant and relationship between ORP and chemical chlorine reaction were investigated in this project. The result shows that when the temperature increases, the pH will decrease and ORP value will also decrease.

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