An Ultrasonic System for Chlorine Measurement in Potable Water

Gabriel W. S. da Silva
Federal Institute of Amazonas
IFAM - CMDI
Manaus, Brazil
gabriel.wsds@hotmail.com

Carlos R. P dos Santos Junior
SENAI Innovation Institute for Microelectronics
Manaus, Brazil
carlos.pereira@am.senai.br

Vitor Bremgartner
Federal Institute of Amazonas
IFAM - CMDI
Manaus, Brazil
vitorbref@ifam.edu.br

Abstract— **Chlorine is the most widely disinfectant used in the treatment of water for human consumption. However, if used in large quantities, it can cause several diseases. This situation has motivated several researchers to develop systems to detect the amount of chlorine in water. This paper proposes an electronic system to analyze water contaminated by chlorine using ultrasonic measurements. Experimental results are presented to show the efficiency of the proposed system.**

Keywords — potable water analysis, chlorine measurement, ultrasonic system

I. INTRODUCTION

Water is the fundamental substance for the existence of the human beings. It is estimated that eighty percent of diseases and about a third of deaths in developing countries, such as Brazil, are caused by the consumption of contaminated water [1]. This contamination mainly affects a specific group of people, among children, infants, the elderly and people already sick.

As a decontamination strategy, one of the solutions used by water companies is to add chlorine to the water that is supplied. When added to water, chlorine neutralizes the action of microorganisms or eliminates them [2]. However, excessive amounts of chlorine can cause unwanted reactions and the creation of carcinogenic organic compounds such as trihalomethanes.

As seen in [3], Brazil usually has cases of chlorine contamination involving public health. Thus, several studies are done to find the best method of chlorine detection, among them the work proposed by [4], which performs chlorine detection using Electrical Impedance Spectroscopy (EIS), seeking to find a mathematical relationship between the spectrum of the electrical impedance of drinking water and the concentration of chlorine found in it, using EIS. The research in [5] also deals with chlorine detection, however using a titration by N, N-diethyl-p-phenylene diamine (DPD), which is an indicator for the presence of residual chlorine, which reacts to the presence of chlorine changing color. Another method developed was described by [6], which detected the presence of chlorine in the water of some bathrooms and laundries using ortolitidine.

This paper presents an ultrasonic system for chlorine measurement in drinking water. The operation of the system is based on the principle that sound propagates with different speeds in different media. The idea is to relate the speed at which the sound propagates in the water with the amount of chlorine present in it, all the chlorine concentration measurement were made using sanitary water, because it has a controlled concentration of chlorine.

The paper is organized as follows: first, in the Section II, is presented the Theoretical Background where the physical and electronic aspects of this research are discussed. After, the development and the description of the proposed system for this paper is presented on Section III. In the Section IV, the experimental results show the efficiency of the system. Lastly, the final considerations are presented in Section V.

II. THEORETICAL BACKGROUND

This section presents theory about ultrasonic transducers and how they work in the system, in addition to the concepts applied to time-to-digital converters.

A. *Ultrasonic transducers*

There are two ultrasonic transducers that act with receivers and transmitters of the generated ultrasonic waves, these being made of piezoelectric ceramics of the type PZT. Using a fixed length pipe, chlorine fluids have parameters such as the wave velocity generated by the transducers in order to calibrate the measuring cell and thus define the time of flight of the water with sanitary water. The transducers used in this paper were projected to work in the frequency of 2 MHz.

B. *Ultrasonic measurements*

Currently, ultrasound is used in many sectors, including the industrial and ever the medical. Since ultrasound consists in a non-destructive method, it can be used to define properties, e. g. fluids such as water and oil [7].

The method of ultrasonic characterization, as it has been said, is a non-destructive method in which a high frequency ultrasonic beam is introduced into the fluid [7], which conducts this type of sound wave to vibration [8]. The ultrasonic wave decreases its intensity according to the propagation in a medium and this due to several factors e. g. the signal mirroring, which occurs due to the non-homogeneity of propagation medium.

Ultrasonic waves can undergo reflection, refraction and diffraction when the ultrasonic beam encounters an interface between media with different acoustic characteristics [9].

III. PROPOSED SYSTEM FOR ULTRASONIC CHLORINE MEASUREMENT

This topic describes the system created including electronic parts, e.g. how the time-to-digital converters work in the system and how to prove if the results acquisitioned are corrects. The system proposed concept can be expanded to identify and characterize other liquids as hydraulic fluids or milk.

The TDC 1000 is connected to two ultrasonic transducers. The MCU is connected to the TDC's via SPI. During the measurement period, the MCU will energize the TDC's and initialize them through the SPI. The process of measuring time of flight is done on the TDC 1000 and the TDC 7200 without interference from the MCU. After completing the process, the measurement data is stored in the TDC 7200. The MCU will search the data for SPI and disconnect the TDC chip to save energy. In the assembled system, the MCU sends the data to the PC (data center), which will process the calculation. The MCU enters low power mode and repeats the entire process after a one second time interval. The block diagram of the proposed system is shown in Fig. 1.

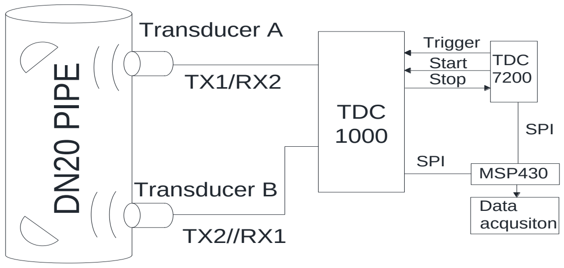

Fig. 1. Block diagram of measurement front end

The measurement setup system is presented in Fig.2, and the experimental analysis and validation was made following the step-by-step of the flowchart in Fig.3.

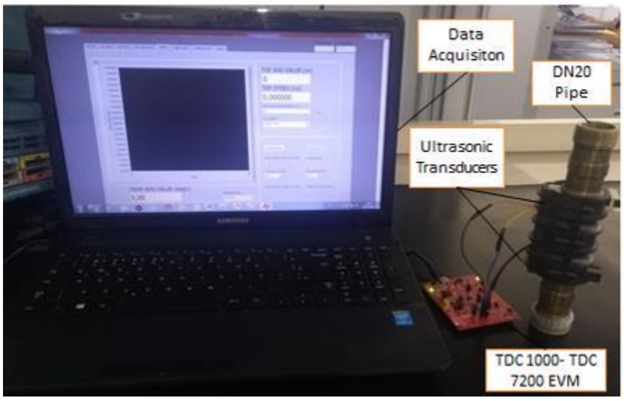

Fig. 2. Measurement setup

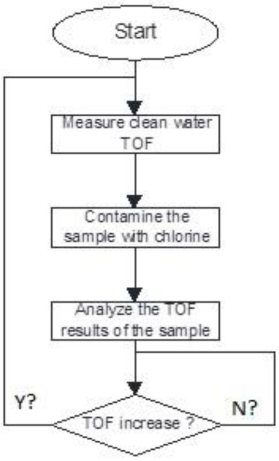

Fig. 3. Measurement system flowchart

The TDC 1000 is an ultrasonic analog-front-end that can be integrated into various measurement systems using ultrasound, such as: identification of fluids, measurement of fluid level and also is useful in medical and automotive areas. This integrated circuit (IC) is used to measure the time of flight of the sample, taking from the transmitter to the receiver transducer. In the measurement process, the MCU sends a start signal to TDC 7200, which will sends a trigger signal to the TDC 1000.

Upon arrival of the received signal, the TDC 1000 amplifies the signal and sends it to comparator that will generate a stop signal and with this, the TDC 7200 will get the time of flight of the sample.

When the start signal is generated by the TDC 1000 the TDC 7200 starts to measure the time of flight using an external clock of 8 MHz. This clock is the basis of time used for generation of the ultrasound signal by the transducers. It is divided up to reach 2 MHz which was the frequency used during the experiments. This IC has 13 register each one with 24 bits only to record the timing information. According [12], when the ultrasonic wave is travelling through the media, a register called “Clock count 1” is responsible to count the number of clock cycle until the first stop signal is received. Another register, “Time 1”, has to measure the time between the start pulse to the rising edge of the 8 MHz clock. Similarly to “Time 1”, there is another register called “Time 2”, that has to measure the time between the stop pulse to the edge of the 8 MHz clock.

Using the information from “Counter 1”, “Time 1” and “Time 2”, it will be possible to calculate the time of flight from the start pulse and stop pulse, in other words is possible to calculate the TOF of the sample.

After the analysis of data, the software TDC1000_7200 is used, which will show the TOF of the wave that went through the entire test piece with the fluid. With this, it is possible to determine the potential contamination of the water, since the TOF of the drinking water will presumably be different from the TOF of the water contaminated by chlorine.

To validate the TOF data received by the transducer and analyzed by TDC 1000- TDC 7200 EVM, must use (1) to the find the correct measures for the time of flight according to the sound velocity, which is approximately 1481 m/s [13].

$$d = TOF \times C \tag{1}$$

d = distance that the sound travels between the transducers sender and receiver.

TOF = Time of flight

C = Speed of sound in water

Eq. 1 is using the parameter "d", as shown if Fig. 4, in other words, the distance will affect the system because the greater distance, the longer time of flight. The measurements were made using a DN20 pipe, which has two internally coupled transducers. The pipe has two mirrors inside that have the function of reflecting the waves generated by the transducers and send them once to one and then to the other, thus, giving greater stability to the system, since the distance between the transducers is fixed.

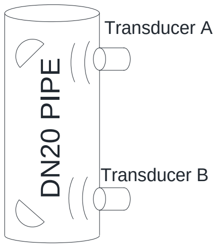

Fig. 4. DN20 pipe with the transducers coupled

TABLE I. ULTRASONIC SYSTEM SETUP

Frequency = 2 MHz
d = 72 mm

IV. EXPERIMENTAL RESULTS

This item shows the results obtained, therefore it is shown how the time of flight of the sample works when there are contamination of chlorine on it, besides generates equations to determine the chlorine concentration and the sample time of flight.

Several tests were initially carried out to verify how chlorine affects each TOF of the contaminated water samples, since sometimes the TOF of the samples can be very similar, as shown in Table II. The tests were done with filtered and boiled water, using the concentrations of 0.1, 0.15, 0.2 and 0.25 mL of sanitary water diluted equivalent to 2.5, 3.75, 5.0 and 6.25 mg of chlorine. The equivalence of the concentration was made using (2), according to [14].

$$SN=0.025*Q \tag{2}$$

SN= Concentration of chlorine in sanitary water in grams

Q= Quantify of sanitary water in milliliters

TABLE II. MEASUREMENTS OF TIME OF FLIGHT IN DIFFERENTS MIXTURES CONCENTRATIONS

Fluids	**TOF Measure 1**	**TOF Measure 2**	**TOF Measure 3**	**TOF Measure 4**
Clean water	63892[a]	63928	63892	63889
Water+sanitary water (0.1 mL)	64395	64418	64422	64407
Water+sanitary water (0.15 mL)	64915	64896	64919	64932
Water+sanitary water (0.2 mL)	64955	64947	64953	64965
Water+sanitary water (0.25 mL)	65341	65342	65326	65336

[a] All TOF units are in micro seconds.

Since there is no internal disturbance other than when the water sample is placed inside the pipe, the system remains stable, with few variations of TOF.

In order to improve the accuracy of the system, the same fluids were evaluated in a time interval of three days, in order to verify if there was some type of later reaction, e. g. the evaporation of chlorine gas and pH alteration of the water. The samples of clean water and the mixture of water with 0.2 ml of sanitary water were chosen. The result was as expected, since with the constant changes in temperature and sample handling, the repeatability presented an error of 12%. With the passage of minutes, the speed of sound usually has small variations due to the instability of the water, which suffers with external variables such as ambient temperature and also with internal variables such as pH.

Due to the small amounts of chlorine present in the sanitary water and by graph scale factors, it was necessary to normalize the concentration values of chlorine, ranging from 2.5 to 6.25 mg and with the normalization of values now vary from 4 to 20. The calculation of equivalence of the scales can be seen in (3).

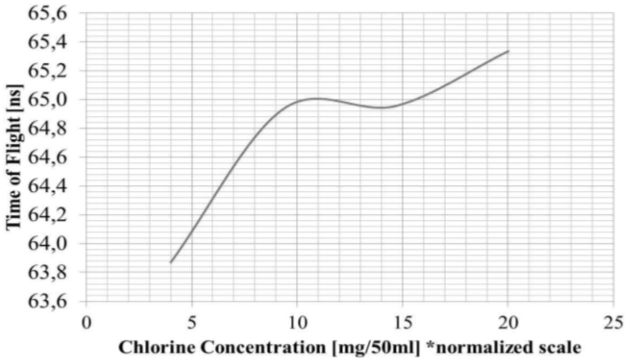

Fig. 5. Time of flight of contaminated water x chlorine concentration

$$CCN= 4.27*[Cl]-6.67 \tag{3}$$

CCN= Chlorine concentration normalized

The mixing of drinking water with sanitary water after three days, showed a variation about 1.1 microseconds difference in relation to drinking water. This happens due to physical properties of the sanitary water used, since its density is approximately 3.4% higher than the water density, which certainly influenced the decrease in sound velocity, decreasing the TOF sample, in addition to the possible leakage of chlorine gas after this time, which may have influenced the decrease in TOF too.

Figure 5 shows the variation of the flight time of each sample of sanitary water mixed with water. It is noted that the increase in the amount of sanitary water, the time of flight increases linearly, tending to higher values with each addition of sanitary water. Analyzing the graph of Fig. 5, the concentration of chlorine in water can be calculated using (4).

$$[Cl] = \{\exp[(TOF-62.752)/0.8693)]+6.67\}/4.27 \tag{4}$$

It is observed that the relationship between the chlorine concentration in the water and the time of flight maintains an approximately linear variation. In Matlab environment, the equation of the line closest to the measurement curve was obtained, as shown in (5).

$$TOF = 0.8693*\ln(4.27*[Cl]-6.67)+62.752 \tag{5}$$

Table III shows estimated chlorine concentration data for each concentration, considering the last data of each time of flight measurement according to Table II, using (4).

TABLE III. ESTIMATED CONCENTRATION OF CHLORINE ACCORDING TO TIME OF FLIGHT MEASUREMENT

Concentration (mg / 50 ml H2O)	Measured TOF in microseconds	Estimated Concentration (mg)	Error
2.50	64407	3.13	25.3%
3.75	64932	4.43	18.3%
5.00	64965	4.5	9.0%
6.25	65336	6.14	1.8%

V. FINAL CONSIDERATIONS

According to the data in the Table III, it is possible to observe that in smaller quantities of chlorine, around 2.5 mg, the presented error is greater due to the low concentration of chlorine, which is mathematically proven by (4).

The system responded to what was proposed, since it was possible to detect the presence of 2.5 mg of chlorine in the water, although there is a significant error, about 25%, a relevant fact, since a large part of the current systems would not identify the difference between the sample with drinking water and water in which it was added chlorine. With increasing chlorine concentration it is possible to note that the error has been decreasing more and more, showing a clear tendency of decay every time chlorine concentration in the sample increases.

It is possible that the water is already contaminated by some other element. In the future we intend to improve the system to work together with other sensors, so that it is possible to create a selection system where other substances are detected.

The chlorine-to-water detection system proved to be satisfactory and extremely fast but, external factors such as temperature and pressure of the environment, besides the pH of the water used, should be considered. It is concluded that ultrasound can be an important tool for the rapid detection of chlorine concentration in drinking water without the application of chemical agents or other types of analysis. However, further research should be done to improve the method of detection of chlorine by ultrasound to verify the concentration of chlorine in any aqueous solution such as tap water and physiological solutions.

ACKNOWLEDGMENT

To SENAI Innovation Institute for Microelectronics and Federal Institute of Amazonas.

REFERENCES

[1] G. H. Galal, "Chlorine in water disinfection," Pure & Appl. Chem. Great Britain, vol. 68, No. 9, pp. 1731-1735, 1996.

[2] L. F. D. Souza, " Study of optimized localization of equipaments for contamination detection in water distribution networks," M. S. Thesis, SHS, EESC, São Carlos, BR, 2006.

[3] C.V.V Rachel, and H. Léo, "Outbreak of hemolytic reactions associated with chlorine and chloramine residuals in hemodialysis water," Rev. Saúde Pública, vol. 35, No. 5, pp. 481-486, July 2001.

[4] D. Dutra, F. B. Pedro, and M. Eduardo, "Detection of chlorine in potable water using electricity impedence spectroscopy."

[5] B. B. B. M. Joaquim, "Simulation of chlorine and trihalomethane species concentrations in water distributuion systems," M. S. Thesis, DEQ, FEUP, Porto, PT, 2005.

[6] J.G. March, M. Gual, and B.M. Simonet, "Determination of residual chlorine in greywater using *o*-tolidine," Els. Sci., vol. 58, pp. 995-1001, August, 2002.

[7] S. B. M. Raphaela, "Ultrasound using to monitoring physical properties of oils," unpublished.

[8] A. B. Laura, " Identification technique of milk adulteration by ultrasound an fuzzy logic," M. S. Thesis, PPGEFT, Limeira, BR, 2015.

[9] A. A. Amauri et al., " System for generating, acquisition, and processing of ultrasound signs," Rev. Cont. Aut., vol. 20, No 2, pp. 145-155, May 2008.

[10] N. S. L. Sérgio, et al., "Characterization of bovine milk using ultrasound and artificial neural networks," Rev. Cont. Aut. vol. 20, No 4, pp. 627-636, December, 2009.

[11] S. Sheen, et al., " An in-line ultrasonic viscometer," Rev. of Prog. in Quant. Nond. Eva., vol. 14a, No 5, pp. 1151-1158, July 1995.

[12] Texas Instruments, "Ultrasonic TDC flowmeter reference design: Data sheet," 2015.

[13] F. O. Ítalo, R. D. Dalto, and S. P. Afonso, " Automated batimetric survey applied to the management of water resources. Case study: damming of riverside São Bartolomeu, Viçosa, Minas Gerais.", in press.

[14] National Fundation of Health, "Household sanitation, instructions of use of sanitary improvements: Instruction manual," 2014.