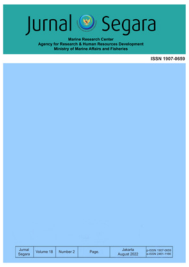

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SALINITY SENSOR DEVELOPMENT FOR POND WATER UTILIZING ULTRASONIC WAVE

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ABSTRACT

Shrimp farming is one of the most popular aquaculture activities in Indonesia. This activity is carried out in a pond. Therefore, there are many ponds as a place for shrimp farming in Indonesia. Several factors affect the results of shrimp farming in ponds. One of the factors is water quality. Four parameters that are commonly used to indicate water quality i.e. dissolve oxygen, salinity, PH, and temperature. In this study, we discussed salinity measurement. Most salinity sensors use the probe principle in measurement. When the sensors are used to measure the water that contains mineral salts, the probe will be susceptible to rust and cause measurement errors. Based on these conditions, we conducted a study of salinity measurements by using the acoustic technique. The measurement was carried out by using an ultrasonic wave. The water salinity was determined based on the acoustic intensity and acoustic speed. In this research, we developed a conversion curve based on the measurement of acoustic intensity from NaCl, KCl, and $MgCl_2$ saline solutions with certain concentrations. The conversion curve is used to measure salinity in pond water. We also calculated salinity based on the measurement result of acoustic speed. From the experiment, the NaCl conversion curve became the most suitable for salinity measurement. The measurement result of salinity in pond water from the NaCl saline solution conversion curve was very close to the results of Del Grosso formula, Chen Millero formula, and refractometer.

Keywords: Acoustic intensity, acoustic speed, conversion curve, & salinity.

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INTRODUCTION

Indonesia has great potential in terms of aquaculture. It may happen because Indonesia has the third longest coastline in the world. One of the most popular aquaculture activities in Indonesia is shrimp farming. It can be seen from shrimp farming results increase every year (KKP, 2021). In order to get more shrimp farming results, water quality must be considered during the shrimp farming process. It has several parameters, i.e. temperature, PH, dissolve oxygen, and salinity (Atmomarsono *et al*., 2014; Supono, 2017). This paper will discuss salinity measurement. The standard of salinity for shrimp pond water is 15 – 35 ppt or 30 – 33 g/l(Badan Standardisasi Nasional, 2014; Suharyadi, 2011; Supito, 2017; Supono, 2017). When salinity in shrimp pond water does not match that standard, it can make those shrimps feel stressed, get some diseases, and even they will die.

Most salinity sensors are made on the principle of a probe that uses two electrodes. These sensors measure salinity levels by immersing the electrode in the water. Mostly shrimp farming uses brackish water. So, these sensors cannot be used to measure salinity levels continuously. When these sensors are immersed in brackish water continuously, there is a potential that will damage those electrodes (Coastal Wiki, 2020; MyScienceCruise, 2016). It makes those electrodes getting worse and giving incorrect measurement results. Based on this condition, we conducted a study of salinity measurement using an acoustic technique from ultrasonic waves.

Several researchers also developed ultrasonic for acoustic wave technology by using high focused ultrasound (Gunawan *et al*., 2013, 2015, 2016; Hoche, Hussein, & Becker, 2015; N. Hozumi *et al*., 2005, 2007, 2013). However, high focused ultrasound is still relatively expensive. In the previous research, range finder ultrasound generated the echo signal to obtain acoustic intensity value and estimated salinity of saline solutions (Gunawan *et al*., 2017; Gunawan *et al*., 2020). However, it still has some deficiencies such as there is the different results when the position of range finder ultrasound was shifted and very high accuracy required in the calculation process because the tail of the echo signal is too long.

In this research, we use a waterproof ultrasonic sensor with a frequency of 40 KHz to generate the acoustic waves. This sensor can be immersed continuously in the water and can touch directly the material (Bakar *et al*., 2017; Talukder *et al*., 2018). By using this sensor, this research builds a tool that can measure the water salinity of shrimp ponds. This tool can measure water salinity continuosly without human assistance and can show the salinity value automatically so the user does not need to check the scale manually. In this research, we have tried to utilize a waterproof ultrasonic sensor to characterize NaCl, KCl, and $MgCl_2$ based on acoustic intensity and acoustic speed. These three types of salt are contained in the water (Apriani *et al*., 2018; Sverdrup *et al*., 1942). From this experiment, we get the acoustic intensity which will be converted to salinity using the conversion curve. We also get the acoustic speed to calculating salinity using Del Grosso and Chen Millero formula.

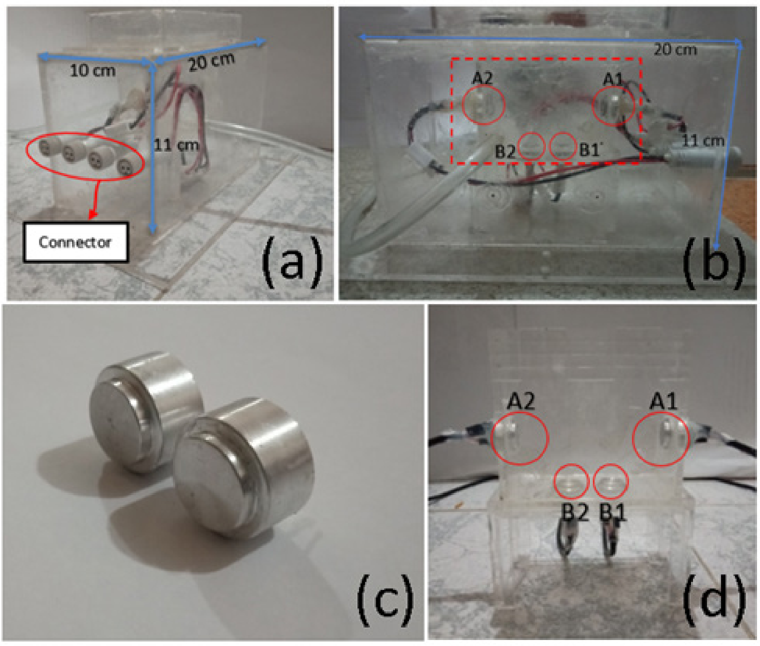

Figure 1. Dimension of Container (a), Position of chamber measurement (b), Waterproof Ultrasonic Sensor (c), sensor configuration (d).

METHODOLOGY

Measurement Chamber

In this study, we developed a container which a small measurement chamber inside it. The container and measurement chamber are made from acrylic material with a thickness of 3 mm. The container is 20 cm x 10 cm x 11 cm as shown in Figure 1a, whether the measurement chamber has 8 cm x 4 cm x 5 cm as shown by the red dash line area in Figure 1b. In the measurement chamber, there are four connectors to connect the sensor with an electronic device as shown in Figure 1a. While inside the measurement chamber we utilize four waterproof ultrasonic sensors the ID of A1, A2, B1, and B2. A1 and B1 are transmitters of waterproof ultrasonic sensors. A2 and B2 are receivers of waterproof ultrasonic sensors. Figure 1c shows the typical sensor we used in this study. Figure 1d shows the configuration of ultrasonic sensors, where A1 and A2 are used for transmission measurement, B1 and B2 are used for reflection measurement.

Block Diagram System

The diagram shown in Figure 2 explains the work of the electronic system. A microcontroller (STM32F4 Discovery) is used for pulse generator and data acquisition. The pulse generator produced an electric pulse and then send to A1 and B1. For transmission measurement, A1 converts the electric pulse into a mechanical pulse and then sends it through the object and received by A2. A2 converts mechanical pulse back to electric pulse and then processed by microcontroller. For the reflection measurement, B1 converts electric pulse into mechanical pulse and then sends it through the object and reflected by the interface between the object and acrylic and received by B2. B2 converts mechanical pulse back to electric pulse and then processed by microcontroller. Since attenuation happened during transmission, 3 V electric pulse from the microcontroller will vanish before being received by A2 and B2. Therefore we need a voltage amplifier to amplify 3 V into 22 V for this system.

Calculation Method

The calculation method of this study was adopted from a previous study. In Gunawan's study, acoustic impedance measurement of body tissues was carried out using a focused transducer (Gunawan *et al*., 2015). In this study, ultrasonic propagation was approached using a single plane wave with measurement methods as shown in Figure 3.

For calculating salinity, we proposed three methods. The first method we utilize Del Grosso formula ("Technical Guides - Speed of Sound in Sea Water - Underlying Physics," 2021). Del Grosso formula as shown in Equation (2). The original Del Grosso formula is used to find speed from salinity. However, in this study, we reverse the formula to obtain salinity from speed. Speed is obtained from the time of flight and distance using Equation (1). The distance is determined from the sensor distance A1 to A2. For time of flight measurement we used threshold. Time of flight measurement process as shown in Figure 5b1 and Figure 5b2. In the same manner, we also used that process for calculating salinity with the second method i.e. Chen Millero formula ("Technical Guides - Speed of Sound in Sea Water - Underlying Physics," 2021). Chen Millero formula as shown in Equation (3).

In the third method, we estimate the salinity value from the acoustic intensity. In this method, we used a conversion curve from acoustic intensity to salinity. Acoustic intensity is obtained using the measurement

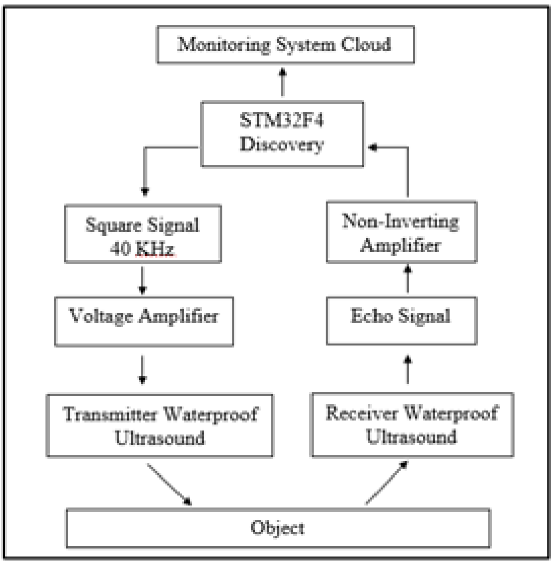

Figure 2. Block diagram system.

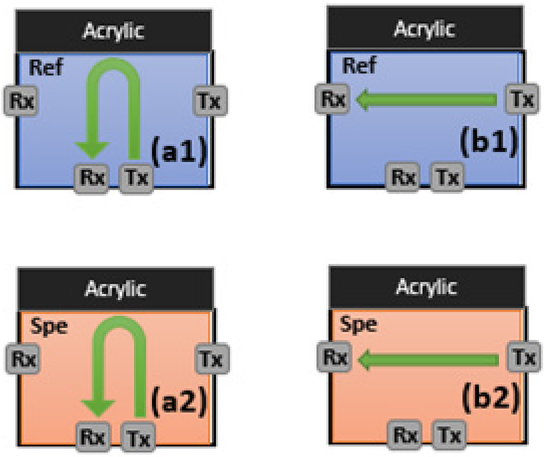

Figure 3. Acoustic intensity measurement (a1) (a2) and acoustic speed measurement (b1) (b2).

process as shown in Figure 3a1 and Figure 3a2 and calculated with equation (4).

$$c = \frac{s}{t} \quad \text{1)}$$

$$c(S,T,P) = C_{000} + \Delta C_T + \Delta C_s + \Delta C_p + \Delta C_{STP} \quad \text{2)}$$

$$c(S,T,P) = Cw(T,P) + A(T,P)S + B(T,P)S^{3/2} + D(T,P)S^2 \quad \text{3)}$$

$$Intensity\ (RMS) = \sqrt{\frac{1}{n}\sum_{i=0}^{n-1}|Vi|^2} \quad \text{4)}$$

RESULTS AND DISCUSSION

Three kind of saline solutions, i.e., NaCl, KCl, and $MgCl_2$ with several concentration (0%, 2%, 4%, 6%, 8%, 10%) are prepared as specimens. Saline solutions with a concentration of 0% - 10% or 0 ppt - 100 ppt are used to develop a conversion curve that includes the salinity of coastal water (30 - 32 ppt) and shrimp pond water (15 - 35 ppt) (Bramawanto & Sagala, 2016; Nurjana, 2016; Supono, 2017). Each specimen is measured in the measurement chamber. Figure 4 shows the result of the echo signal from NaCl saline solutions measurement with concentrations of 0% - 10%.

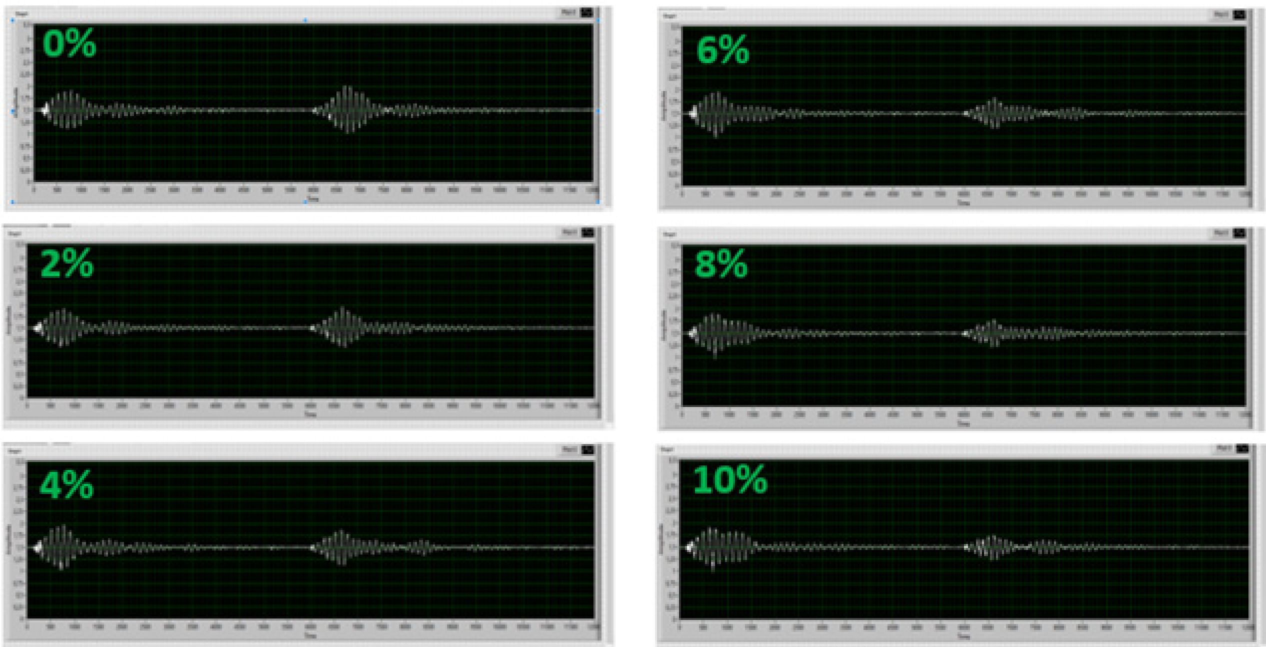

Figure 4. From top to down, echo signal from NaCl saline solutions with concentration 0%, 2%, 4%, 6%, 8% and 10%..

Table 1. Field observation results

Saline Solutions (%)	Intensity						Normalized		
	NaCl		KCl		$MgCl_2$		NaCl	KCl	$MgCl_2$
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation			
0%	1.500225	0.000073	1.500225	0.000073	1.500225	0.000073	1.000000	1.000000	1.000000
2%	1.500038	0.000011	1.500045	0.000026	1.499839	0.000020	0.999876	0.999880	0.999742
4%	1.499657	0.000028	1.499577	0.000027	1.499737	0.000028	0.999622	0.999568	0.999675
6%	1.499277	0.000036	1.499360	0.000025	1.499527	0.000030	0.999368	0.999424	0.999535
8%	1.499091	0.000061	1.499075	0.000091	1.499358	0.000005	0.999244	0.999234	0.999422
10%	1.498832	0.000038	1.498752	0.000043	1.499128	0.000011	0.999072	0.999018	0.999269

As shown in Figure 6a, there are two waves shape, i.e. reflection wave (inside of red rectangle) and transmission wave (inside of blue rectangle). The reflection wave is transmitted by B1 and received by B2. This wave is used to obtain acoustic intensity from Vrms by using Equation 4. Vrms is calculated from the beginning until the end of the signal. From the result shown in Figure 4, it can be seen that the reflection wave from 0% to 10% is decreased. It is mean that the acoustic intensity also decreases. By doing the same manner we also obtain the result of the experiment from KCl and $MgCl_2$. The acoustic intensity results are an average of 10 data. Table 1 shows the acoustic intensity calculated in RMS of NaCl, KCl, and $MgCl_2$ solutions.

While the transmission wave is transmitted by A1 and receive d by A2. This wave is used to obtain acoustic speed from the time of flight. Time of flight is calculated when the wave is transmitted by A1 until received by A2. This process as shown in Figure 6a (inside of an orange rectangle). The time of flight is calculated from the starting point of the signal or the zero point to the first point when the signal passes the threshold. Figure 5 shows the method used to calculate the time of flight from the transmission signal, where the red line is the threshold and the inside of the yellow circle is the first point that passes the threshold. Figure 6b shows the distance between A1 and A2 is 6.8 cm. Then the acoustic speed in the pure water is 1480 m/s.

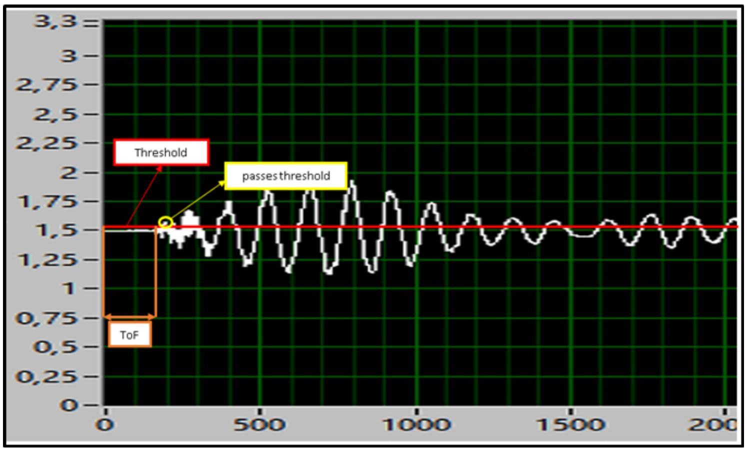

Figure 5. Time of flight calculation method.

Table 2. Measurement of acoustic speed from saline solutions.

Saline Solutions (%)	Time of Flight (us)						Acoustic Speed (m/s)		
	NaCl		KCl		$MgCl_2$		NaCl	KCl	$MgCl_2$
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation			
0%	46.48	0.19	46.48	0.19	46.48	0.19	1462.99	1462.99	1462.99
2%	45.16	0.13	45.56	0.13	45.56	0.13	1505.75	1492.54	1492.54
4%	44.44	0.23	44.48	0.17	44.72	0.17	1530.15	1528.78	1520.57
6%	43.56	0.13	43.68	0.17	43.68	0.17	1561.07	1556.77	1556.77
8%	42.08	0.17	42.24	0.21	43.20	0.00	1615.97	1609.85	1574.07
10%	41.36	0.21	41.36	0.21	42.44	0.12	1644.10	1644.10	1602.26

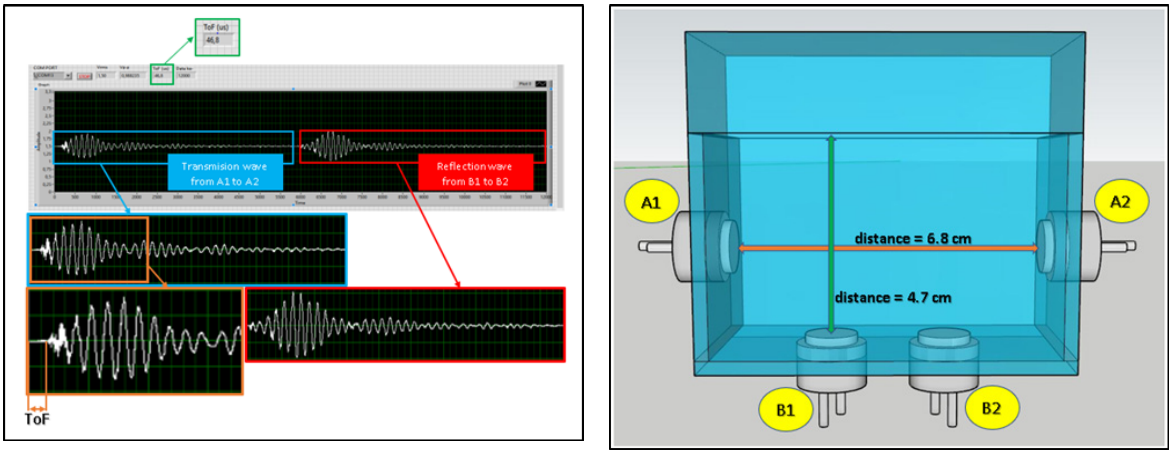

Figure 6. Transmission wave and reflected wave (a), The distance of two sensors (b).

The time of flight can be calculated by using Equation 1. The result of the time of flight by theoretical calculation in Equation 1 is 45.94 us. The result of time of flight from pure water by experiment is 46.48 us. This experiment result of time of flight is an average of 10 data. There is no significant difference between the result from the calculation using Equation 1 and the experiment. So we decided that this manner can be used for obtaining time of flight for another concentration. Table 2 shows the time of flight and acoustic speed of NaCl, KCl, and $MgCl_2$ solutions.

Figure 7 shows plotted data between intensity and percent of salinity based on three saline solutions

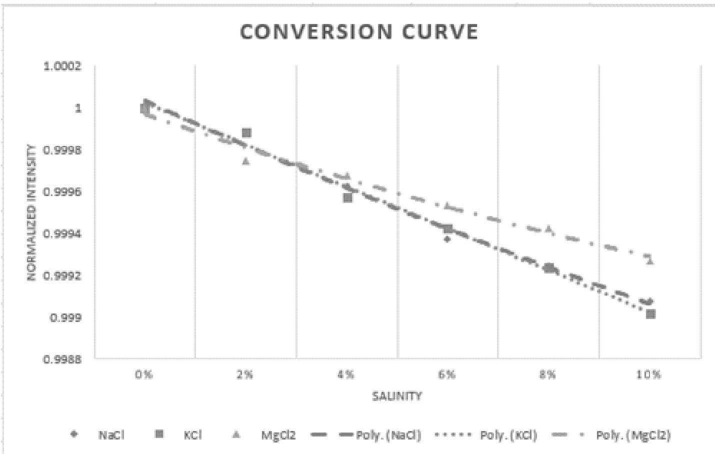

Figure 7. Conversion curve from saline solutions.

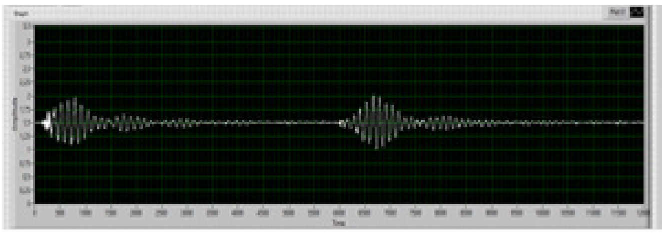

Figure 8. Echo signal from first pond water measurement.

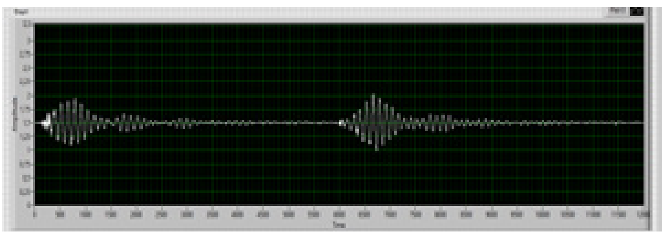

Figure 9. Echo signal from second pond water measurement.

Table 3. Acoustic speed and intensity of pond water measurement..

Object Test	Acoustic Intensity (V)	Time of Flight (us)	Acoustic Speed (m/s)
Pond Water I	1.500218	46	1510.22
Pond Water II	1.500223	46.027	1509.32

Table 4. Estimation of salinity in pond water based on acoustic speed and intensity.

Object Test	Salinity (ppt)					
	NaCl	KCl	$MgCl_2$	Del Grosso	Chen Millero	Refractometer
Pond Water I	4.16	3.06	2.43	4.176	4.427	4
Pond Water II	3.63	2.57	1.72	3.507	3.783	3

shown in Table 1. From these data, we can develop a conversion curve, which can convert the data of intensity into percent of salinity. After making a conversion curve from saline solutions with a concentration of 0% - 10%, it shows that there is no significant difference between the three curves. However, we only tested up to saline solutions with a concentration of 10% because the salinity standard in pond water is already covered within that range. Salinity estimation is done by entering normalized acoustic intensity into the conversion curve equation of NaCl, KCl, and $MgCl_2$ as shown in Equation (5), Equation (6), and Equation (7).

$$y = 0.000001x^2 - 0.00011x + 1.000032 \quad \text{......... 5)}$$

$$y = 0.00000004x^2 - 0.00010024x + 1.00002057 \quad \text{... 6)}$$

$$y = 0.000002x^2 - 0.000083x + 0.999967 \quad \text{............... 7)}$$

In the next process, we validate the result of this research on the formula that has been obtained as shown in Equation (2), Equation (3), Equation (5), Equation (6), and Equation (7). To validate these three methods, we measure pond water taken from the different ponds. For Del Grosso and Chen Millero formula, we have to get the information of acoustic speed as shown in Figure 8 and Figure 9. From the figure, we obtain the data of time of flight and acoustic speed as shown in Table 3. While the conversion curve in Equation (5), Equation (6), and Equation (7) are done by measuring the intensity (RMS). Table 3 shows the data of acoustic intensity (RMS).

Table 4 shows salinity results from three methods and the salinity meter standard (refractometer). The Refractometer is calibrated by placing distilled water on the prism assembly, then closing the cover plate, looking into the eyepiece, and turning the calibration screw with the screwdriver until the reading is 0 ppt. After the instrument has been calibrated, It is used to measure the salinity of pond water by placing a water sample on a prism assembly and look the salinity value in the eyepiece. Structure diagram of refractometer as shown in Figure 10.

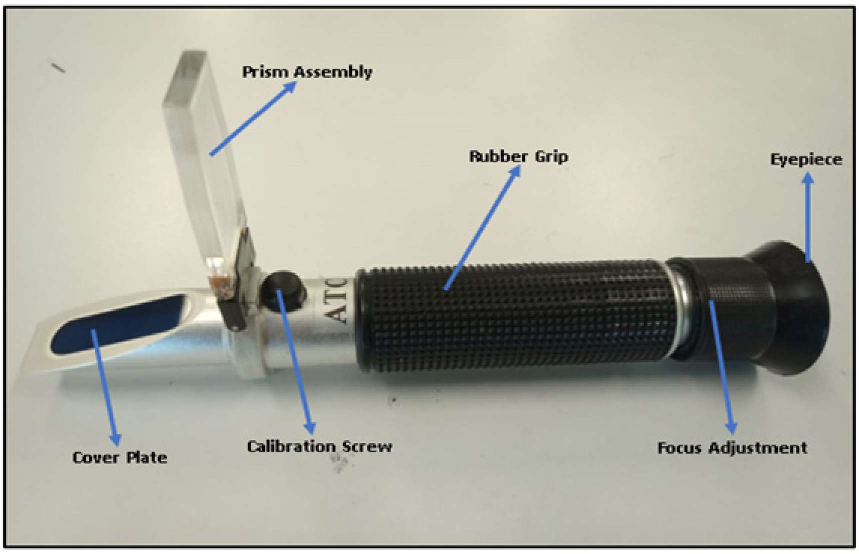

Figure 10. Structure diagram of refractometer.

Dell Grosso and Chen Millero are standard equations used by UNESCO to determine salinity based on acoustic speed. While the calibration curve is a development based on previous research (Gunawan *et al*., 2020). The result of salinity measurement using Del Grosso is close to Chen Millero. While the results of salinity measurement using the NaCl conversion curve are closer to the results from Del Grosso and Chen Millero when compared to KCl and $MgCl_2$ conversion curves. This is because the largest salt content for water in East Java is NaCl (Apriani *et al*., 2018). In addition, when the Del Grosso and Chen Millero formulas were found the sample for creating these formulas is taken from the North Atlantic sea, where sodium (Na) and chlorine (Cl) become the largest content in the water next to oxygen and hydrogen(Forchhammer, 1865; Millero, 2010). So in this research, we hypothesized that in two tested pond water, NaCl is the largest salt content. This hypothesis is also confirmed by measurement using a refractometer whose results are close to measurement using the NaCl conversion curve.

CONCLUSION

In this research, a salinity estimation system using an ultrasonic sensor was developed. The salinity is estimated based on two methods utilizing acoustic intensity and acoustic speed.

Acoustic intensity is used to obtain salinity based on a conversion curve that converts acoustic intensity into salinity. Three kinds of conversion curves created from NaCl, KCl, and MgClF are successfully established. In another hand, acoustic speed is used to obtain salinity based on Del Grosso and Chen Millero formula. These three kinds of conversion curves and two models from Del Grosso and Chen Millero formula are compared to the result from the refractometer utilizing two different unknown pond water. There is no significant difference in the results between the three kinds of conversion curves. However, because the largest salt content for water in East Java is NaCl, it is better to use a conversion curve from the NaCl saline solution(Apriani *et al*., 2018).

From the experiment, The result of salinity measurement from pond water I and pond water II using the NaCl calibration curve are very close to the result of Del Grosso formula, Chen Millero formula, and measurement using a refractometer. So we hypothesized that two tested pond water are rich of NaCl and decide that the NaCl conversion curve is most suitable for salinity measurement.

ACKOWLEDGEMENTS

In this research, a salinity estimation system using an ultrasonic sensor was developed. The salinity is estimated based on two methods utilizing acoustic intensity and acoustic speed.

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