# Estimation of Liquid Parameters using Arduino based Ultrasonic Rangefinder Sensor

**Asia Pacific Journal of Multidisciplinary Research**
Vol. 8 No.1, 126-133
February 2020
P-ISSN 2350-7756
E-ISSN 2350-8442
www.apjmr.com
ASEAN Citation Index

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*Date Received: November 1, 2019; Date Revised: February 8, 2020*

**Abstract -** *There are a number of physical and control variables that affect the optimal monitoring of industrial and commercial processes in industries and power plants. The variables involved in the processes generally include the physical phase of occurrence of matter, temperature, pressure, density and level. All level measurement systems rely upon various characteristics of the process materials such as density, capacitance and temperature and has its own benefits and limitations. Depending on the nature of process materials, level estimation of liquids can be broadly classified into contact methods and non-contact methods. Ultrasonic method of non-contact type sensors interfaced with Arduino Uno is highly preferable for estimating the level of corrosive and non-corrosive liquids and fluids. The Arduino Uno an open-source microcontroller board possess a number of facilities for communicating with external systems such as computers and sensors. By determining the level, various other parameters such as density, pressure and bulk modulus of the fluid can also be estimated which affects the industrial processes.*

**Keywords:** *Level Measurement, Process control, Arduino Uno, Liquid parameters, Non-contact method, Open source microcontroller, Optimal monitoring, Rangefinder sensor.*

## INTRODUCTION

The quality of measurement is of paramount importance in any process control industry or power plant. Process control plays a vital role in monitoring and controlling certain set of process variables such as temperature, pressure, level and flow for any given process. The liquid state is one among the primary states by which the matter exists. The atoms and molecules of the liquid phase are closer to each other but the chemical bonding which exists between the atoms and molecules are not much rigid as in the case of solid phase. The liquid phase possesses a high degree of freedom which contributes for the relative motion between the atoms and molecules. Integral to process control in many industries, various parameters are generally required to be monitored and controlled accurately which can be a determining factor both in terms of profitable margin and safety. Owing to the importance of level measurement and the innumerable different process materials requiring level measurement, a number of methods are available in industries and power plants. All level measurement systems rely on the nature of application and the level of accuracy required.

Based on the methods of level measurement, they are broadly classified into two namely: contact and non-contact types of measurement. The process materials in industries are generally classified as normal liquid state, granular solids, slurry type fluids and state of interface. Liquids generally are corrosive and non corrosive in nature and depending on the variation in pressure, temperature and density various types of sensors can be implemented in industries. Non contact methods are highly preferable when the materials used for measurement are corrosive in nature and may cause damage to sensors if brought in contact with the surface of measurement. It is also beneficial when the nature of medium is agitated, and when temperature and pressure of the processes affects the reading of the sensor. Numerous types of non-contact methods of level measurement are available. Ultrasonic method of non contact type is highly effective and efficient as compared to numerous methods that are available in industries [1]. The current study deals with the measurement of various parameters of different solutions using ultrasonic sensor. The ultrasonic sensor has various benefits over other methods of measurements.

Differential pressure transmitters are usually subjected to density variations of solutions. They are usually applied to clean solutions. The Bubblers and Displacer type of pressure gauges involved in plants are usually affected by variation in density. Variation in density is usually incurred during the processes owing to variation temperature changes and change of product mixtures. Electrical capacitance type of level measurement involves a constant dielectric transmitter and receiver system type of liquid flow. Any change in the liquid nature results in compensation of the system. Ultrasonic type of sensor has a high degree of precision in estimator response even after the chemical composition of the solution varies. It also has the additional feature of estimating the various parameters without having any physical contact with the substances being measured. These features of Ultrasonic sensors besides being inexpensive in nature add to the advantages of the sensor to be used in the industries and power plants for estimation of various parameters of solutions.

The Arduino Uno based ultrasonic sensor intends to make the process environment to be much more accessible. Being an open source with simplified and user friendly programming language Arduino Uno assists in compatible and effective way of measuring the level for any given process. Various other parameters can also be estimated by the determination of level for a given liquid state of the process using the chemical thermodynamic relations that exists between them. In this paper, we focus on the determination of level of the water solution in a measuring cylinder using the Arduino Uno based ultrasonic sensor and compare the results with that of the true value of the level of water in the measuring cylinder .The static error percentage is hence calculated. Further, the level of various other solutions such as a mixture of sodium hydroxide and water and a mixture of acetanilide and water was measured using the sensor. Various other parameters of the solution such as density, pressure, bulk modulus and temperature for the second and third analysis were estimated. The performance of the sensor for a complete solvent (water solution), further for a solute completely soluble in solvent (solution of NaOH) and finally for a solute slightly soluble in solute (solution of acetanilide) was analyzed.

The remaining section of this paper is organized as follows: Section 2 discusses the over view of the experimental setup with principle of construction and working of the non contact type Arduino Uno based ultrasonic sensor. Section 3 briefs about the experimental procedures, evaluation and estimation of the various parameters of the solutions. Section 4 contains the conclusion and future scope.

## MATERIALS AND METHODS

### Overview of the Experimental Set up

The basic block diagram of the experimental setup is as shown in Figure 1

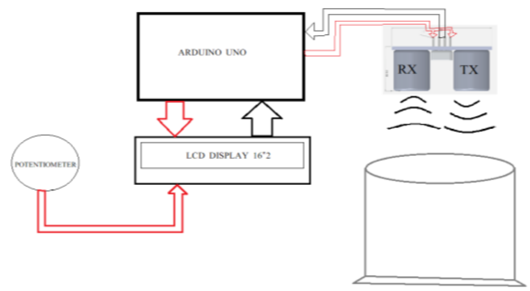


**Figure 1.** Block diagram of the Experimental Set-up.

Ultrasonic waves are vibration of frequencies greater than the upper limit of audible range for human i.e. greater than about 20 kHz[2]. Ultrasonic waves propagate with the speed of sound in air as about 343m/s at 20°C [3]. The wavelength of the sound waves is generally shorter, owing to which a higher resolution of distance and direction of propagation can be obtained. Ultrasonic waves cannot travel through vacuum and their velocity remains constant in homogeneous media. They have the property to produce vibrations in low viscosity fluids. Similar to light waves, sound waves also possess the properties of reflection and refraction and obey the Snell's law of refraction. The speed of ultrasonic waves is more in denser medium than in a rarer medium. When ultrasonic waves traverse through a non homogeneous media, the amplitude and intensity of the wave signal correspondingly decreases when they come across some discontinuities or cracks during the propagation of the wave. The attenuation increases with increase in frequency of ultrasonic waves for a given medium. Based on the above mentioned properties, HC-SR04 ultrasonic sensor was selected for the production of ultrasonic waves. The principle of generation of ultrasonic waves is the inverse Piezo-electric effect discovered by the physicists Jacques Curie and Pierre Curie in1880.If an electric field is applied to one pair of faces, the corresponding changes in the dimensions on the other pair of faces of the crystal are produced, owing to which ultrasonic waves are generated. The sensor used in the experimental analysis uses the principle of *Time of flight* concept of ultrasonic waves. The acoustic ultrasonic sensor consists of a transmitting and receiving head. The transmitter emits the ultrasonic waves which propagate through the air with a frequency of 4MHz. The sensor requires an operating voltage of 5Vand operating current less than15 mA. The range of liquid level which is taken for analysis must be in the range of 2 to 400 cm. The angle of propagation of ultrasonic waves is in the range of 30°. Once the ultrasonic waves comes in contact with the liquid under analysis, the Echo pin of the sensor is raised high for a short period based on the time taken by the ultrasonic waves to bounce back to the receiver at the receiving end. The distance propagated by the ultrasonic waves is directly proportional to the time the wave takes from the transmitting to the receiving end. The amount of time taken is proportional to the amount of distance taken by the ultrasonic wave to propagate. The Trig pin of the sensor is kept high for a time period of 10µS when the transmitter head is switched on. The waves propagate with the speed of sound creating 8 cycles, which are subsequently collected by the Echo pin of the sensor. The total distance is calculated using the *Pulse Reflection method equation* which is given by (1)

$$s= (v \times t) / 2. \quad (1)$$

where 's' is the distance required in cm, 'v' is the speed with which the sound propagates in cm/S and 't' is the time of propagation for transmission and reflection of the sound waves in S.

The ultrasonic sensor is interfaced with Arduino Uno microcontroller in order to measure the level of liquid. The Arduino Uno board is a microcontroller based on ATmega328 which consists of 14 digital input and output pins. Out of the 14 pins, 6 can be used as pulse width modulated outputs. It also comprises of a 16 MHz ceramic resonator, an ICSP header, 6 analog inputs, a USB connection, a power jack and a reset button respectively. In order to begin, the system is connected to a computer with a USB cable or a battery. This mode of connection helps in serial communication. It consists of a 32 KB flash memory in order to store the programming code. The level of the liquid in the measuring cylinder is displayed using a liquid crystal display. The liquid crystal display used in the analysis is usually an electro-optical based amplitude modulated device made up of a number of monochrome pixels arrayed such that the reflected light beam from the liquid level is allowed to focus on to the arranged pixels there by displaying the level of liquid. The 16x2 LCD module was used in the analysis. The potentiometer is used as a voltage divider to obtain a manually adjustable voltage from the fixed input voltage applied across the two ends of it to adjust the contrast of the LCD display.

The Arduino board is connected through a USB to the Arduino Development Environment (ADE). The Arduino code is written in the ADE and further uploaded to the microcontroller which in turn executes the code, there by interacting with the inputs and outputs respectively.The sensor was initially used to determine the level of water solution in a measuring cylinder. Subsequently, the sensor was used to determine the levels of a solution of sodium hydroxide and a solution of acetanilide. Further, various parameters related to the solutions based on the level of liquid were determined using the mathematical relations between the fluid properties.

## RESULTS AND DISCUSSION

### Determination and Estimation of the various Liquid Parameters

### Determination of level for a Solution of water

A volume of 100 ml was initially filled in a measuring cylinder. The level of water was determined with the help of the designed sensor subsequently. The water level was gradually increased up to a volume of 550 ml and the levels were correspondingly determined. The determined level was then compared with that of the true value. The static percentage error was calculated and is shown in Table 1.

As the volume of water is increased from 100 ml gradually in steps of 50 ml at each interval, the actual distance measured using the designed ultrasonic sensor is comparatively less than that of the nominal distance which is measured from the graduated measuring cylinder whose measured length is 44.5 cm. It is observed that the estimated level using the sensor increases with that of the calculated nominal values. The static error percentage is determined and the comparison curve between the actual and nominal distance is shown in Figure 2.

Table 1. Estimation of Level for Water Solution

| S.No. | Volume of water (l) | Actual distance using sensor (m) | Nominal distance (m) | Actual Level using sensor (m) | Nominal Level (m) | % Error |
|---|---|---|---|---|---|---|
| 1 | 0.1 | 0.38 | 0.3886 | 0.065 | 0.0564 | 2.21 |
| 2 | 0.15 | 0.36 | 0.3733 | 0.085 | 0.0717 | 3.56 |
| 3 | 0.2 | 0.34 | 0.3556 | 0.105 | 0.0894 | 4.39 |
| 4 | 0.25 | 0.33 | 0.347 | 0.115 | 0.098 | 4.90 |
| 5 | 0.3 | 0.32 | 0.332 | 0.125 | 0.113 | 3.61 |
| 6 | 0.35 | 0.31 | 0.3111 | 0.135 | 0.1339 | 0.35 |
| 7 | 0.4 | 0.28 | 0.2946 | 0.165 | 0.1504 | 4.96 |
| 8 | 0.45 | 0.27 | 0.2768 | 0.175 | 0.1682 | 2.46 |
| 9 | 0.5 | 0.25 | 0.2604 | 0.195 | 0.1846 | 3.99 |
| 10 | 0.55 | 0.23 | 0.2438 | 0.215 | 0.2012 | 5.66 |

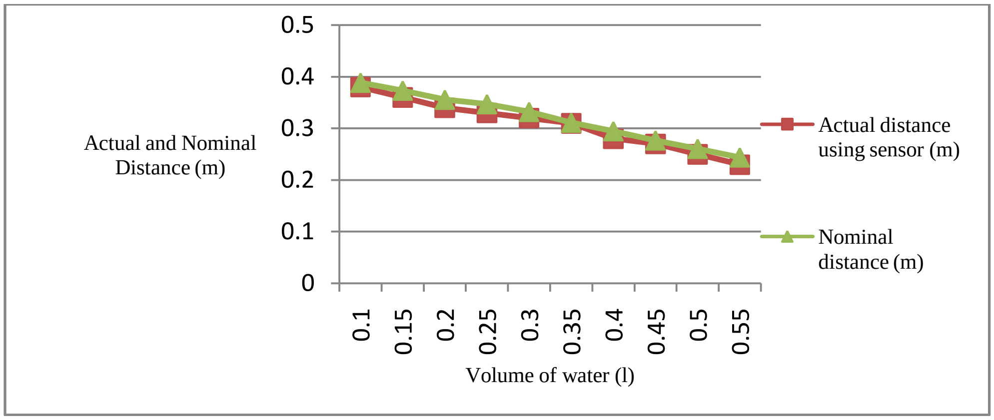


**Figure 2.** Comparison between actual distance and nominal distance for solution of water

**Table 2.** Estimation of Level for Sodium hydroxide Solution

| S.No. | Volume of solution (l) | Actual distance using sensor (m) | Nominal distance (m) | Actual Level using sensor (m) | Nominal Level (m) | % Error |
|---|---|---|---|---|---|---|
| 1 | 0.115 | 0.37 | 0.3962 | 0.075 | 0.0488 | 6.61 |
| 2 | 0.165 | 0.36 | 0.38 | 0.085 | 0.065 | 5.26 |
| 3 | 0.215 | 0.34 | 0.3632 | 0.105 | 0.0818 | 6.39 |
| 4 | 0.265 | 0.33 | 0.3454 | 0.115 | 0.0996 | 4.46 |
| 5 | 0.315 | 0.31 | 0.3302 | 0.135 | 0.1148 | 6.12 |
| 6 | 0.365 | 0.3 | 0.3136 | 0.145 | 0.1314 | 4.34 |
| 7 | 0.415 | 0.28 | 0.2984 | 0.165 | 0.1466 | 6.17 |
| 8 | 0.465 | 0.26 | 0.2819 | 0.185 | 0.1631 | 7.77 |
| 9 | 0.515 | 0.25 | 0.2641 | 0.195 | 0.1809 | 5.34 |
| 10 | 0.565 | 0.23 | 0.2476 | 0.215 | 0.1974 | 7.11 |

**Estimation of various parameters for a solution of sodium hydroxide**

A standard amount of 15 g of NaOH is mixed with water solution of 100 ml. Further upon, the level of the solution is increased from 100 ml to 550 ml by correspondingly increasing the solvent by adding an amount of 50 ml at each interval and the corresponding level of the solution was determined using the sensor. As the level of solution is increased, there was a corresponding change in temperature. The above mentioned process is an exothermic reaction, where heat is generally evolved. As the level of the solution increases, the temperature of the solution decreases. The temperature gradient for the given solution was determined using mercury thermometer at each interval. Further the true level of the solution in the measuring cylinder was also determined. The static percentage error was calculated and is shown in Table 2.

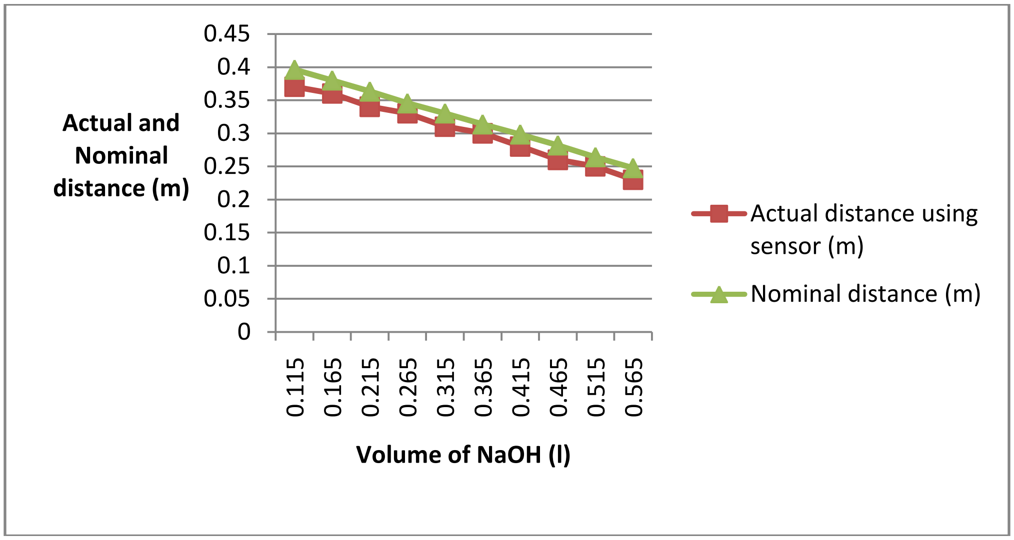


**Figure 3** Comparison between actual distance and nominal distance for solution of NaOH

From Table 2, as the volume of water is increased from 100 ml gradually in steps of 50 ml at each interval, for a standard amount of solute of 50 g the actual distance measured using the designed ultrasonic sensor is comparatively less than that of the nominal distance. The estimated level using the sensor increases with that of the calculated nominal values. The static error percentage is determined and the comparison curve between the actual and nominal distance is shown in Figure 3.

The theoretical density of the composite mixture is an intensive property. The theoretical density is computed based on the general thermodynamic formula which is given by

$$\rho = \text{mass}/\text{volume}. \qquad (2)$$

where, 'ρ' represents the theoretical density in $kg/m^3$. The theoretical pressure of the given solution is given by the principle of Hydrostatic Law [4], Using the equation

$$P = \rho g h \text{ pascal} \qquad (3)$$

where 'P' represents the pressure measured in pascal, 'g' is acceleration due to gravity, $9.8m/S^2$ and ' h' is the height of the liquid column in measuring cylinder in 'm'.

The pressure variation can be determined for the liquid. In a uniform gravitational field, liquid pressure depends on depth. In a liquid at rest, the frictional and inertial stresses are not accountable. When this condition is applied to Navier-Stokes equation, the pressure gradient becomes a function of body forces. The estimated value of pressure gradually increases with depth as the temperature decreases. The estimated pressure is determined at the bottom surface of the cylinder as the volume of the water is increased. The estimated density gradually decreases with respect to the change in volume.

The Bulk Modulus of the fluid is a measure of the resistance offered by the fluid to a compressive force acting on it. It is the measure of the decrease in volume with an increase in pressure gradient. The bulk modulus of a liquid is a measure of the compressibility of the liquid. A combination of Young's modulus, shear modulus and Hooke's Law, the Bulk Modulus factor describes a material's response to stress or strain. Mathematically, bulk modulus is expressed as,

$$K = dp / -(dV/V) \qquad (4)$$

where 'K' is the bulk modulus in $newton/m^2$ , 'dV' is the change in volume from an initial volume 'V' corresponding to a change in pressure 'dp'. With respect to the change in maximum volume of 565 ml, the corresponding bulk modulus is determined for the liquid. The temperature of the liquid in the measuring cylinder decreases with the rise in liquid level, as the reaction between sodium hydroxide and water is an exothermic reaction where heat is evolved. As the volume of the solution in the measuring cylinder increases, the estimated values of the bulk modulus increases. The Table 3 gives a complete detail of the estimation of various parameters for the given solution of sodium hydroxide.

**Table 3. Estimation of various parameters for NaOH solution**

| S.No. | Total Volume of NaOH solution (l) | Temperature (°C ) | Density (kg/m$^3$) | Height of liquid column'h' (m) | Pressure (pascal) | Bulk Modulus 'K' (pascal) |
|---|---|---|---|---|---|---|
| 1 | 0.115 | 44 | 1009 | 0.10 | 988.82 | |
| 2 | 0.165 | 38 | 1001 | 0.15 | 1471.47 | 1592.75 |
| 3 | 0.215 | 35 | 999 | 0.20 | 1958.04 | 2092.25 |
| 4 | 0.265 | 32 | 998 | 0.25 | 2445.10 | 2581.42 |
| 5 | 0.315 | 31 | 997 | 0.30 | 2931.180 | 3062.30 |
| 6 | 0.365 | 30 | 996 | 0.35 | 3416..80 | 3545.03 |
| 7 | 0.415 | 29 | 996 | 0.40 | 3904.32 | 4046.42 |
| 8 | 0.465 | 28 | 997 | 0.45 | 4396.77 | 4579.79 |
| 9 | 0.515 | 28 | 996 | 0.50 | 4880.40 | 4981.39 |
| 10 | 0.565 | 27 | 996 | 0.55 | 5368.44 | 5514.85 |

**Estimation of various parameters for a solution of Acetenilide**

Acetenilide is an odourless solid chemical of flake like appearance. It is slightly soluble in water and is mostly stable under most conditions. 10 g of acetenilide is added with100 ml water solution. The liquid level of the solution is increased from 100 ml to 550 ml and the corresponding level of the solution was determined using the sensor. As the level of solution is increased, a constant temperature of 26 degree Celsius was maintained. The constant temperature for the given solution was determined using a mercury thermometer. The true level of the solution in the measuring cylinder was then determined. The static error was calculated and is shown in Table 4.

From Table 4, as the volume of water is increased from 100 ml gradually in steps of 50 ml at each interval, for a constant amount of solute of 10 g the actual distance measured using the designed ultrasonic sensor is comparatively less than that of the nominal distance. The estimated level using the sensor increases with that of the calculated nominal values. The static error percentage is determined and the comparison curve between the actual and nominal distance is shown in Figure 4.

**Table 4.** Estimation of Level for Acetenilide Solution

| S.No. | Volume of solution (l) | Actual distance using sensor (m) | Nominal distance (m) | Actual Level using sensor (m) | Nominal Level (m) | % Error |
|---|---|---|---|---|---|---|
| 1 | 0.11 | 0.38 | 0.39 | 0.07 | 0.05 | 3.53 |
| 2 | 0.165 | 0.36 | 0.38 | 0.09 | 0.07 | 4.86 |
| 3 | 0.215 | 0.34 | 0.36 | 0.11 | 0.09 | 5.56 |
| 4 | 0.265 | 0.33 | 0.35 | 0.12 | 0.10 | 4.46 |
| 5 | 0.315 | 0.31 | 0.33 | 0.14 | 0.12 | 4.64 |
| 6 | 0.365 | 0.3 | 0.31 | 0.15 | 0.13 | 3.97 |
| 7 | 0.415 | 0.28 | 0.30 | 0.17 | 0.15 | 5.76 |
| 8 | 0.465 | 0.27 | 0.28 | 0.18 | 0.17 | 2.46 |
| 9 | 0.515 | 0.25 | 0.26 | 0.20 | 0.18 | 4.43 |
| 10 | 0.565 | 0.23 | 0.25 | 0.22 | 0.20 | 6.62 |

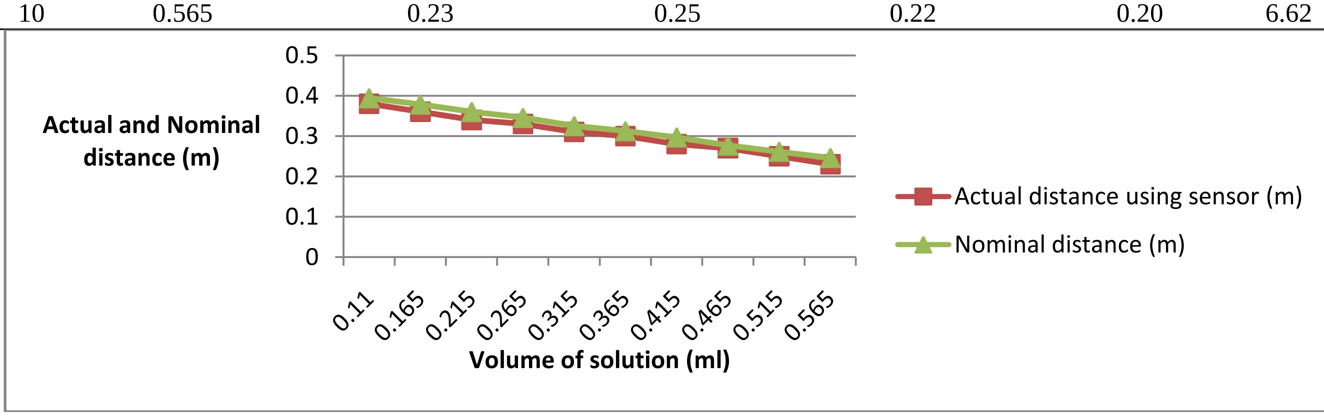


***Figure 4*** *Comparison between actual distance and nominal distance for solution of Acetenilide*

**Table 5. Estimation of various parameters for Acetenilide solution**

| S.No. | Total Volume of Acetenilide solution (l) | Density ($kg/m^3$) | Height of liquid column 'h' (m) | Pressure (pascal) | Bulk Modulus 'K' (pascal) |
|---|---|---|---|---|---|
| 1 | 0.11 | 1017 | 0.1 | 996.66 | |
| 2 | 0.16 | 1011 | 0.15 | 1486.17 | 1566.432 |
| 3 | 0.21 | 1007 | 0.2 | 1973.72 | 2047.71 |
| 4 | 0.26 | 1005 | 0.25 | 2462.25 | 2540.356 |
| 5 | 0.31 | 1004 | 0.3 | 2951.76 | 3034.962 |
| 6 | 0.36 | 1003 | 0.35 | 3440.29 | 3517.416 |
| 7 | 0.41 | 1002 | 0.4 | 3927.84 | 3997.91 |
| 8 | 0.46 | 1002 | 0.45 | 4418.82 | 4517.016 |
| 9 | 0.51 | 1001 | 0.5 | 4904.9 | 4958.016 |
| 10 | 0.56 | 1001 | 0.55 | 5395.39 | 5493.488 |

The density, theoretical pressure variation along with bulk modulus for the given liquid solution was determined similar to the procedure adopted for the sodium hydroxide solution. The temperature of the solution is observed to be 24°C and is constant throughout the experiment. The pressure of the experimental system gradually increases with depth as the volume increases. The density of the solution gradually decreases with respect to the change in volume. The bulk modulus of the solution increases with the change in level of the solution. The estimated values are shown in Table 5.

## CONCLUSION

The designed ultrasonic based Arduino sensor was used to determine the parameters of different types of solutions. Initially a solution of water was taken. Further, a known amount of sodium hydroxide taken was completely dissolved in the water solution. Finally a known amount of acetanilide was taken and was mixed with water solution. The first analysis was on a complete water solution. The second analysis was a mixture of solvent and solute, where the standard amount of solute was completely dissolved in the solvent to make up a solution. In the final analysis, the standard amount of solute was insoluble in the solvent. The Arduino based ultrasonic sensor designed was intended to measure the various parameters of the above mentioned different solutions. The designed sensor was effective and simple in construction and was highly efficient in estimating the parameters of the various solutions.

The percentage of error indicated by the sensor measurement was the least for the analysis of water solution alone. The maximum error percentage was indicated for the solution of NaOH. The presence of errors between the estimated and nominal value occurs due to various factors. While the reflection of sound takes place between the transmitter and receiver, the speed of sound in air changes with humidity and temperature. The equation that can be accounted for these factors is given by

$$c = 331.4 + (0.606*T) + (0.0124*H). \qquad (5)$$

where, c is the speed of sound in m / S, 331.4 is the speed of sound in m / S at 0°C and 0 % humidity, T is the temperature in °C and H is the relative humidity in %. To compensate for temperature based errors, a thermistor can be added in the designed circuit. Thus the errors due to temperature can be compensated and accuracy would be increased. The humidity in the above equation can be measured and compensated using the DHT11 humidity sensor. Thus the physical parameters temperature and humidity would be compensated using the *Steinhart-Hart equation* by measuring them using the above techniques [5]. Transient characteristics and irregular shapes and sizes of the ultrasonic sensor also contribute towards the limitations of this sensor which must be compensated for [6].

The Arduino based designed ultrasonic sensor can be compensated for the errors using the above mentioned techniques. The current study involves the measurement of level, pressure, density and bulk modulus for the given set of different solutions. The primary measurement involved the measurement of level for a solution of water. Further the various parameters were measured for a solution of sodium hydroxide, where the solvent was allowed to be dissolved in the solute. Further the study was extended to a sample of acetanilide mixed with water. This sample was almost insoluble in water. The three different sets of samples involving only water solution, a sample almost dissolved in water solution and lastly a sample almost insoluble in water was taken and the parameters were estimated. The Ultrasonic sensor using Arduino served as a medium of measurement with more precision in all three cases and the characteristic curves were obtained. The current study can be applied for solutions and fluids at rest, but cannot be extended to studies involving fluids in motions. The study can be further modified to measure the fluids in motion using the principles of *Doppler Effect and Time Transit method* where the distance of the moving particles in the fluid are generally taken into account. Using the above mentioned techniques future investigations can be carried out for fluids in motion.

## ACKNOWLEDGMENT

The author would like to thank the staff members and officials of College of Engineering and Technology Mai Nefhi for providing the necessary facilities and equipments for carrying out this research.

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## Appendix

The Arduino based program coding for the operation of Ultrasonic Rangefinder sensor is as follows:

```
#include <LiquidCrystal.h>
LiquidCrystallcd (1,2,4,5,6,7);
constinttrigPin=11;
constintechoPin=10;
long duration;
int distance;
void setup()
{
  lcd.begin(16,2);
  pinMode(trigPin,OUTPUT);
  pinMode(echoPin,INPUT);
}
void loop()
{
  (trigPin,LOW);
  delay(2);
  digitalWrite(trigPin,HIGH);
  delay(10);
  digitalWrite(trigPin,LOW);
  duration=pulseIn(echoPin,HIGH);
  distance=duration*(0.034/2);
  lcd.setCursor(0,0);
  lcd.print("DISTANCE\n:");
  lcd.print(distance);
  lcd.print("cm \n");
  delay(10);
 }
```

### COPYRIGHTS



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