Characterization of Capacitive Sensor for Measurement of Urea In Bovine Urine

Haritha J, Valarmathi R S, Arun Chendhuran R, Aravind S, Balamurugan V T

Abstract: ***A capacitive sensing probe is suggested to detect the concentration of urea in bovine urine samples. The variation in the relativepermittivity of the medium measures the change in capacitance, magnitude and phase parameters due to the change in concentration of urea in bovine urine. The sensor characteristics are observed for the simulating frequencies of 100Hz, 1 kHz, and 10 kHz and20kHz for the entire experiment. It is observed that there is a linear increment in magnitude and phase accompanied with a linear decrement in the capacitance. The sensor can identify a range from 10mg to 100mg of urea per ml of urine. It is also obvious that change in capacitance is better compared to the magnitude and phase variations of the sensing probe.***

Keywords: Urea, bovine urine, capacitance.

I. INTRODUCTION

Urea is the final waste product of degradation of protein into nitrogen com-pounds as a result of tissue metabolism. The urea travels in blood from liver and excreted through urine from kidney [1].Being an important biomarker its level in the urine and blood are monitored periodically which gives the nutritional levels of liver and kidney [2]. The urea level for a normal healthy human body is 20-40 mg/dl. However there may be an elevation in this range due to pathophysiological conditions and ageing. Serious problem in human body like Azotemia [3] which finally cause uremia or uremic syndrome may be raised due to the higher concentration of urea levels in blood and in urine it may leads to renal dysfunction, urinary tract obstruction, dehydration, diabetes, shock, burns, and gastrointestinal bleeding [4] [5] [6].The decrement in the status of urea levels in urine may cause severe liver disease, malnutrition, hepatic failure, nephritic syndrome, and cachexia [4].Hence, the determination of urea levels in urine plays an important role.

Analytical methods are enhanced for urea detection such as fluorimetry [7], high-performance liquid chromatography [8] surface plasmon resonance [9], enzymatic assay [10] [11], calorimetry [12], electrochemistry [13] [14], gas chromatography [15].

Several techniques are available in the previous works to determine the urea levels in urine which are the most complex analytical methods that need specialized technical expertise and this determination of urea is in influential in various fields like foods science, agricultural processes, environmental monitoring and medical diagnosis. Non-enzymatic piezoelectric sensor based on the modification of molecularly imprinted TiO_2 was used to detect urea concentration in urine [8]. Spectrophotometric method was the first method to determine the urea by urease enzyme which is developed by Watt and Crisp. Later this method was modified by using alcoholic Ehrlich reagent [3].On the other hand, catalyzed hydrolysis of ammonia may be used for urea detection .Universally, potentiometric method is the most commonly used method for urea detection. The major disadvantages of this method is sensitivity and metal ion interference effects[16].In addition, Calorimetry, fluorimetry and gas chromatography are conventional methods for detection of urea concentration in urine [17].

Materials and Methods

Optimal selection of Sensor

The construction of an open ended cylindrical probe consists of two hollow cylinders varying in inner and outer diameter. The inner cylinder has the inner and outer diameter as 10mm and 8mm respectively whereas the outer diameter has the inner and the outer diameter as 19mm and 17mm.The two hollow cylinders are at a constant height of 50mm .The two electrodes which evolves from the two cylinders leads to LCR meter. These two sensors are dipped into the sample solution at a depth of 20mm.The depth of the sensor is constantly maintained and monitored. The LCR meter is used to study the characteristics of the sensor in both magnitude and phase mode.

Sensor design

As cited above capacitive sensor has been used. The assembly of the capacitive sensor is made up of an open ended cylindrical probe. The dielectric medium used in the project is urine whose urea levels have to be measured. There are some governing factors which leads to change in capacitance value in cylindrical probe. Those factors are namely the area of the plates, the distance between the plates and the dielectric medium between the plates.

The governing factors for an open ended cylindrical probe may be specified as namely the length of an open ended cylindrical probe, the inner radius of the outer cylinder, the outer radius of the inner cylinder and the dielectric medium between the two cylinders. These factors can be depicted mathematically as

Revised Manuscript Received on December 08, 2018.

HarithaJ, Department of Electronics and Instrumentation Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, India

Valarmathi R S, Department of Electronics and Communication Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, India

ArunChendhuran R, Department of Electronics and Instrumentation Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, India

Aravind S, Department of Electronics and Instrumentation Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, India

Balamurugan V T, Department of Electronics and Instrumentation Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, India

$C = ((\pi\varepsilon_r\varepsilon_0 / \ln(r_b/r_a))L$………………………………. (1)

As mentioned earlier ε_0 = 8.854 $x10^{-12}m^{-3}\ kg^{-1}s^4A^2$; ε_r= Relative permittivity of the medium. Here,'L' represents the length of an open ended cylindrical probe, '$_{ra}$' stands for outer radius of the inner cylinder and 'r_b' signifies an inner radius for the outer cylinder.

For an open ended cylindrical probe, the dielectric medium which covers the surface of the sensor is expressed mathematically by

Total surface area = 2π (ra-rb) h…………………… (2)

Where h = height of an open ended sensor which is dipped inside the dielectric medium; 'ra' represents the inner radius of the outer cylinder and 'rb' shows the outer radius of the inner cylinder. The change in the dielectric medium causes the change in the capacitance of the sensor. Sensors are selected based on the two criteria.Change in capacitance with the change in concentration of the sample solution is considered at first followed by the least deviation in the constant capacitance at the given medium.

Investigation Procedure

Experimental procedure is started at normal temperature and pressure (NTP) with fresh urine sample collected from the farm. To test the urea in urine, the sensor is first dipped inside the fresh urine sample and the capacitance is noted for reference. The designed probe is dipped 20mm inside the sample of urine to be tested. Urea is added to 100 ml of urine sample in steps of 1g to 10g.The capacitance, magnitude and phase of the sensor are logged for every 15 minutes after preparation(mixing using a magnetic stirrer) of each sample so that the added urea reaches an equilibrium condition in the urine sample.

Statistical Analysis

Urea concentrations in urine were correlated with LCR meter readings via, capacitances, magnitudes and phase using least square regression analysis. Regression analysis was performed for all frequencies.

Results

A standard LCR meter (Agilent 4263B LCR meter) is used for measuring the change in magnitude, phase and capacitance in the test samples for investigating the characteristics of the sensor. The experiment is carried out at four different frequencies via, 100Hz, 1 kHz, 10 kHz and 20 kHz. The Pearson's r value, slope and intercepts for all the four frequencies with respect to magnitude, phase and capacitance is determined using linear regression analysis and the results are shown in Table 1.

II. DISCUSSION

For the sensor selection, the main criterion considered is its sensitivity. The characteristics are observed using a standard LCR meter (Agilent 4263B LCR meter). The entire experiment is carried out under normal temperature and pressure. Each reading is repeated thrice to check the reproducibility of the sensor. For every gram of urea added to 100ml of fresh urine sample, capacitance, magnitude and phase is noted from the LCR meter. The experiment is a carried out at a frequency range from 100Hz to 20 kHz. It is observed that the sensor exhibits high linearity and has good sensitivity at 100Hz frequency for magnitude, phase and capacitances (Figure 1, figure 2 and figure 3).

The corresponding regression analysis shows Pearson's coefficient, r values as 0.89 for magnitude (Figure 1(a)), 0.78 for phase (Figure 2(a)) and -0.98 for capacitance (Figure 3(a)) at 100Hz frequency. The result also shows that capacitance variation is much better than magnitude and phase variations. Hence the change in capacitance is the main criteria to detect the variation in urea concentration in urine.

Frequency (Hz)	Pearson's r			Slope, intercept		
	Magnitude (Ohm)	Phase (degree)	Capacitance (µF)	Magnitude (Ohm)	Phase (degree)	Capacitance (µF)
100	0.89	0.78	-0.98	0.49, 20.11	0.58, -46.95	-1, 108.19
1k	0.74	0.41	-0.93	0.33,7.9	0.52, -32.42	-0.72, 37.67
10k	0.62	-0.21	-0.97	0.24, 3.84	-0.17, -18.21	-0.2, 11.94
20k	0.46	0.77	-0.97	0.14, 3.56	3.15, -18.87	-0.14, 9.37

Table 1: Readings of Pearson's r, slope and intercept for magnitude, phase and capacitance change in the cylindrical Probe with respect to variation in concentration of urea at four different frequencies viz., 100Hz, 1 kHz, 10 kHz and 20 kHz

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

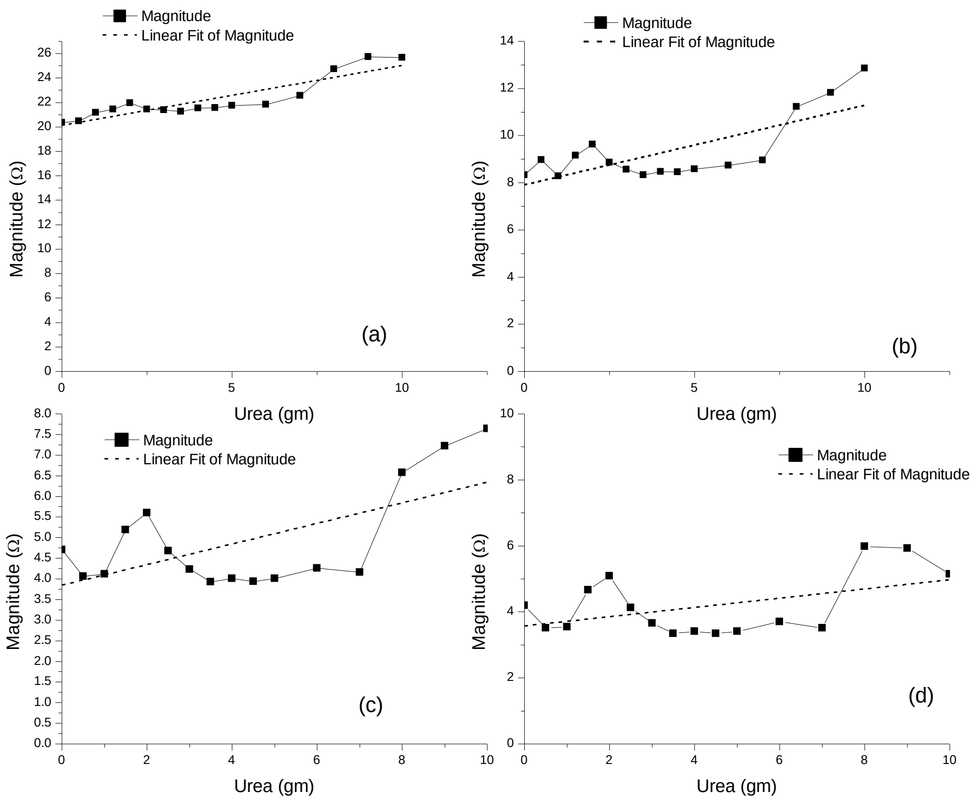

Figure 1: Plot of variation in magnitude at different frequencies (a) 100Hz, (b) 1 kHz, (c) 10 kHz, (d) 20 kHz and it also shows that there is a linear increment with respect to variation in urea concentration.

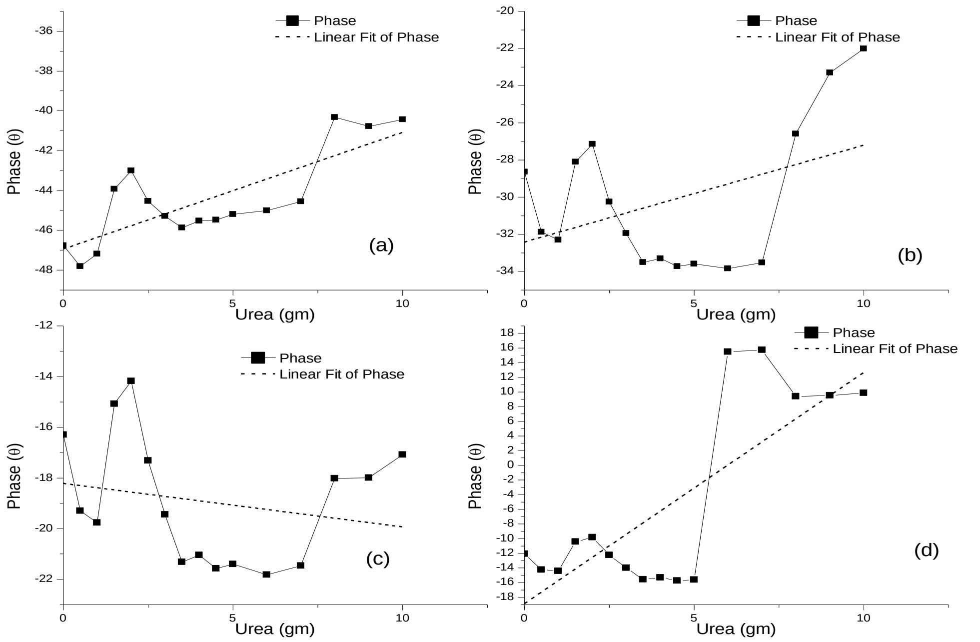

Figure 2: Plot of variation in phase at different frequencies (a)100Hz, (b)1kHz, (c)10kHz, (d)20kHz and it also shows that there is a linear increment with respect to variation in urea concentration.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

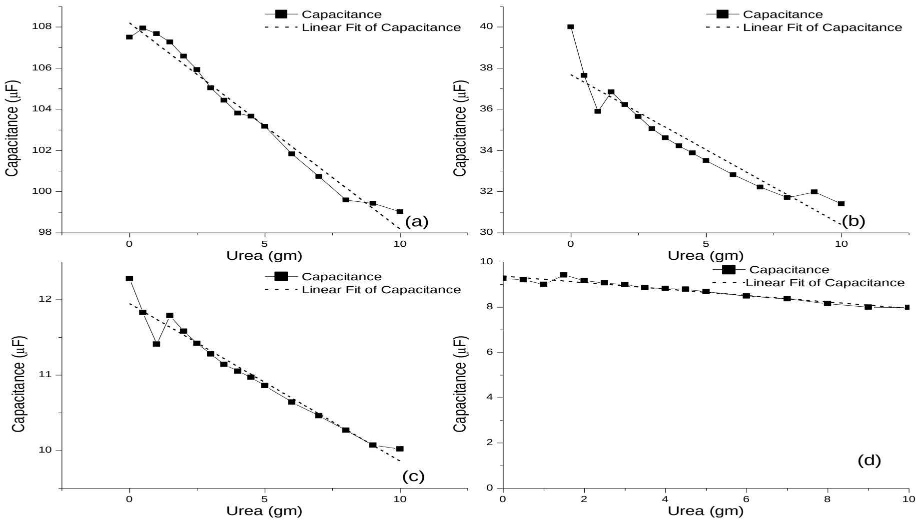

Figure 3: Plot of variation in capacitance at different frequencies (a)100Hz, (b)1kHz, (c)10kHz, (d)20kHz and it also shows that there is a linear decrement with respect to variation in urea concentration.

III. CONCLUSION

In this work, a preliminary study on the characteristics of a cylindrical sensing probe for the variation of urea concentration in the bovine urine samples is done. The resultsprove that the sensor can differentiate the urea concentration variation by observing the magnitude, phase and capacitance of the sensor using a standard LCR meter. However the capacitance obtained from the fresh bovine urine with normal urea need to be considered as a reference sample. Any deviation from the reference value indicates an increment or decrement in urea concentration in urine. It is observed that there is a linear increment for magnitude and phase value and there is a linear decrement in capacitance value for the sensor. Also, the results prove that capacitance change has a high significance compared to the magnitude and phase. Further, a detailed study is required to design a signal conditioning circuit to measure the variation in urea concentration based on the change in capacitance of the cylindrical probe.

ACKNOWLEDGEMENTS

This project is supported by 'Banner Amman Educational Trust - Sathyamangalam, Erode (TN) – India', extending all the available academic and laboratory facilities. We thank

'Bannari Amman Cattle Farm - Sathyamangalam, Erode (TN) – India' for providing the urine samples for testing.

REFERENCES

1. Manuel Gutierrez, Salvador Alegret, and Maneldel Valle. Bioelectronic tongue for the simultaneous determination of urea, creatinine and alkaline ions in clinical samples. Biosensors and Bioelectronics, 23(6):795 - 802, 2008.
2. J.W. Spek, A. Bannink, G. Gort, W.H. Hendriks, and J. Dijkstra. Interaction between dietary content of protein and sodium chloride on milk urea concentration, urinary urea excretion, renal recycling of urea, and urea transfer to the gastrointestinal tract in dairy cows. Journal of Dairy Science, 96(9):5734 - 5745, 2013.
3. Adnan Khan Hamayun Khan SajjadHaiderTahseen Kamal Nauman Ali, Muhammad Ismail. Spectrophotometric methods for the determination of urea in real samples using silver nanoparticles by standard addition and 2nd order derivative methods. Elseiver, page 110, 2017.
4. KanchanmalaDeshpande Sunil BhandGeetesh K. Mishra, Atul Sharma. Flow injection analysis biosensor for urea analysis in urine using enzyme thermistor. 174(3):998-1009, 2014.
5. Marchenko S. V., Kucherenko I. S., Soldatkin O. O., and Soldatkin A. P. Potentiometric biosensor system based on recombinant urease and creatininedeiminase for urea and creatinine determination in blood dialysate and serum. Electro analysis, 27(7):1699-1706.
6. Ahmad, NirmalyaTripathy, and Yoon-Bong Hahn. Highly stable urea sensor based on ZnOnanorods directly grown on Ag/glass electrodes. Sensors and Actuators B: Chemical, 194:290 - 295, 2014.
7. Francoise Roch-Ramel. An enzymic and fluorophotometric method for estimating urea concentrations in nanoliter specimens. Analytical Biochemistry, 21(3):372 - 381, 1967.
8. Zhengpeng Yang, Xianguang Shang, Chunjing Zhang, and Jian-ping Zhu. Photoelectrochemical bilirubin biosensor based on fe3o4/hydroxyapatite/molecularly imprinted polypyrrole nanoparticles. Sensors and Actuators B: Chemical, 201:167 - 172, 2014.
9. RoliVerma and Banshi D. Gupta. A novel approach for simultaneous sensing of urea and glucose by SPR based optical fiber multianalyte sensor. Analyst, 139:1449-1455, 2014.
10. Anita Hamilton and Carmel Breslin. The development of a novel urea sensor using polypyrrole. 145:19-26, 11 2014.
11. Jose Roberto SiqueiraJr, Denise Molinnus, Stefan Beging, and Michael J Schoening. Incorporating a hybrid urease-carbon nanotubes sensitive Nano film on capacitive field-effect sensors for urea detection. 86, 05 2014.
12. Paul S. Francis, Simon W. Lewis, and Kieran F. Lim. Analytical method-ology for the determination of urea: current practice and future trends. TrAC Trends in Analytical Chemistry, 21(5):389 - 400, 2002.
13. SubrataMondal and M.V. Sangaranarayanan. A novel non-enzymatic sensor for urea using a polypyrrole-coated platinum electrode. Sensors and Actuators B: Chemical, 177:478 - 486, 2013.
14. RashmiChaudhari, Abhijeet Joshi, and RohitSrivastava. Ph and urea estimation in urine samples using single fluorophore and ratiometric fluorescent biosensors. Scientific Reports, 7(1):5840, 2017.
15. A Kessler and L Siekmann. Measurement of urea in human serum by isotope dilution mass spectrometry: A reference procedure. 45:1523-9, 10 1999.
16. TaherAlizadeh, Mohammad Reza Ganjali, and Faride Ra ei. Trace level and highly selective determination of urea in various real samples based upon voltammetric analysis of diacetylmonoxime-urea reaction product on the carbon nanotube/carbon paste electrode. AnalyticaChimicaActa, 974:54 - 62, 2017.
17. MuawiaAlqasaimeh, Lee YookHeng, Musa Ahmad, A.S. Santhana Raj, and Tan Ling. A large response range re ectometric urea biosensor made from silica-gel nanoparticles. Sensors, 14(7):13186-13209, 2014.