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Current Research Trends, Future Challenges and Limitations of Biosensor Technology

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Abstract:

The biosensor is an analytical device used to find biological analytes both in quantity and presence. After detection, it uses a transducer to transform the biological response into an electrical signal. Nowadays biosensors are used in a variety of fields, including the medical industry, the pharmaceutical industry, the food industry, environmental monitoring, agriculture, and the military. Different types of biosensors are being created, and each type is based on a unique set of application-specific principles. Biosensors can essentially serve as low-cost and highly efficient devices for this purpose in addition to being used in other day to- day applications. In this article we present the basics of biosensing devices which can serve as an introductory tutorial for readers who are new to this field. Subsequently we provide high-level descriptions of a few representative biosensors as case studies, followed by a brief discussion of the major difficulties the biosensor research communities normally encounter with current research trends, future challenges and limitations of biosensor technology.

Keywords: Biosensor, Transducer, Biosensing devices, Biomolecules, Biological element.

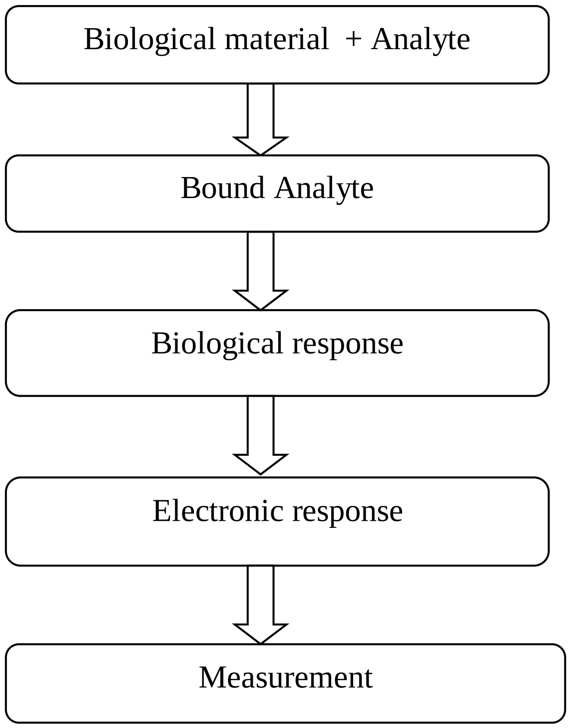
Introduction:

A sensor is a device that measures physical quantity and converts it into a signal which can be read by an observer or by an instrument. Biosensor is an analytical device which converts biological response into an electrical signal. It detects, records and transmit information regarding a physiological change or process. It consists of physical component and biological component. Physical component contain transducer and amplifier and biological component consist sensitive bio element and analyte. The history of biosensors started in the year 1962 with the development of enzyme electrodes by the scientist Leland C. Clark who is called father of biosensor invented the Clark Oxygen Electrode, a pivotal device that allows real time monitoring of patients blood oxygen level and has made surgery safer and more successful for million around the world[1]. A biosensor is an analytical device which contains an immobilized biological material such as enzymes, antibodies, nucleic acid and whole cell. It detects records and transmits information related to physical change and also determines the presence and concentration of specific substance in any test solution. Linearity, sensitivity, selectivity, response time these are the characteristics of biosensors. In this technical world biosensor is very popular and nowadays it is used everywhere in the various fields such as biotechnology, electronics-Smart watches, physics, mechanical, environmental field ,medical field-Glucometer used to detect sugar level it is useful for diabetic patient and pregnancy kit detects the HCG protein in urine[2].

Fig 1: Biosensors

Principle:

A transducer that transforms the data into electrical impulses and a biological sensing component are combined to form a biosensor. There will also be an electronic circuit made up of a processor or microcontroller, a display unit, and a signal conditioning unit. Conventional techniques, such as physical or membrane entrapment, non-covalent or covalent binding, are used to immobilise biological material. The transducer is in contact with this biological material that has been immobilised[3]. The analyte is a substance whose concentration needs to be determined, such as glucose urea, a medication, or a pesticide. It diffuses from the fluid to the biosensor's surface where it interacts with biological material to cause a reaction. This interaction modifies the physicochemical characteristics of the transducer surface, which results in a measurable electrical response.



Advantages :

1. By using biosensor detect harmful chemicals, biological agents inside the human body.

2. Biosensor is economical in use so day by day the use of biosensor is increases.

3. Biosensor is easy to handle for example diabetic patient easy handle regularly glucometer

4. Fast response time.

5. Biosensor is highly stable.

6. Biosensor is highly sensitive.

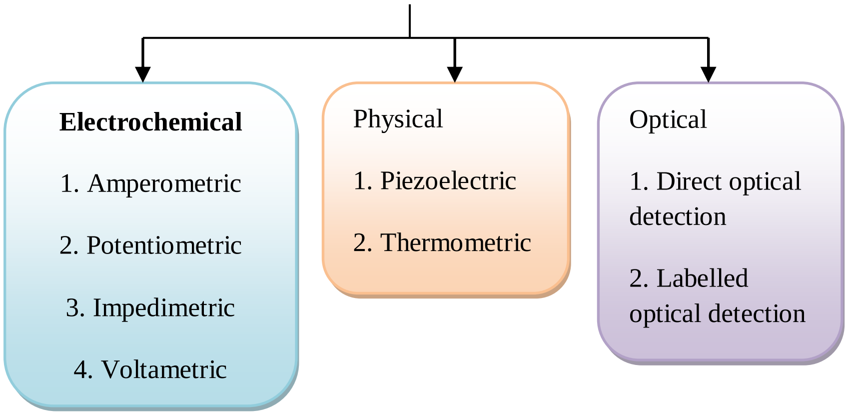
7. Biosensor is capable for repeated use.

8. Biosensor give fast response time.

9. Biosensor have rapid and continuous measurement[10].

Types of Biosensor:

Types of biosensor



A) Electrochemical Biosensor

This biosensor combines the sensitivity of electro analytical method with inherent bioselectivity of biological component. It is based on the principle, many chemical reactions produces or consumes ions or electron which in turn cause some changes in the electrical properties of the solution which can be sensed out and used as measuring parameter. It consists of amperometric biosensor, potentiometric biosensor and conductometric biosensor .

1) Amperometric Biosensor:

This biosensor contain enzyme electrode or chemically modified electrode which is based on movement of electron and it results in enzyme catalyzed redox reaction. A redox reaction catalyzed by enzyme is directly coupled to an electrode where enzyme is present with oxidizable substrate then the electrons are transformed from substrate to electrode via enzyme and redox mediators[16]. The magnitude of current is propertional to the substrate concentration. Most common amperometric biosensor is glucose biosensor which is based on Clark oxygen electrode.

Example: Glucose Biosensor-

This biosensor majorly used to measure blood glucose level. Detection of glucose is important in day to day life of human being. Glucose measurements involves interactions of glucose with one of three enzymes: hexokinase, glucose oxidase (GOx) or glucose-1-dehydrogenase (GDH) [4-5]. In this glucose reacts with glucose oxidase to form glucoronic acid and glucose mediadors reacts with surrounding oxygen to form hydrogen peroxidase and glucose oxidase. Now formed glucose oxidase react with glucose to form glucoronic acid and this reaction consume oxygen. Higher the glucose content higher is the oxygen consumption. Then glucose content is determined by platinium electrode[6].

$$\text{Glucose} + O_2 \xrightarrow{\text{glucose oxidase}} \text{Glucoronic acid} + H_2O_2$$

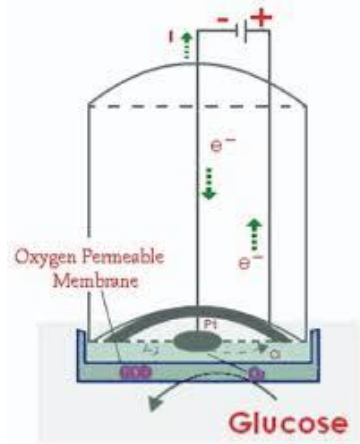


Fig 2: Glucose biosensor

2) Potentiometric Biosensor:

Potentiometric biosensor is a type of chemical sensor that used to determine the analytical concentration of components of analyte gas or solution. It consists of membrane containing immobilized enzyme and surrounding the probe from a pH meter[7]. This biosensor based on oxidation or reduction potential of an electrochemical reaction. In this, signal is measured as potential difference between reference and standard electrode which is proportional to concentration of substrate. When voltage applied to an electrode in solution then current flow occurs because of electrochemical reaction. A voltage at which this reaction occurs indicates a particular reaction. The working electrode's potential depends on the concentration of the analyte in the gas or solution phase and reference electrode is needed to provide required reference potential[8].

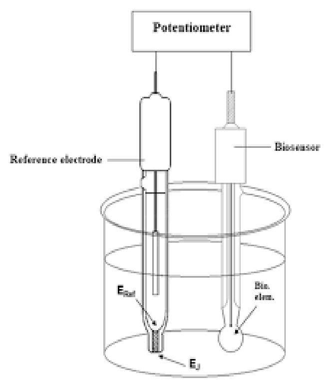


Fig 3: Potentiometric Biosensor.

3) Conductometric Biosensor:

In conductometric biosensor the measured parameter is electrical conductance. Conductivity of liquid is due to dissociation of dissolved substance, an electrolyte into ions and migration of the latter induced by an electrical field[9]. Conductivity measurement is based on the biocatalytic reaction of sample on an electrode. It consists of reference and working electrode which is coated with a nata de coco membrane. Enzyme is immobilized on working electrode. The reaction produces ions which results in the change of conducty. Urea biosensor is an example of conductometric biosensor[9].

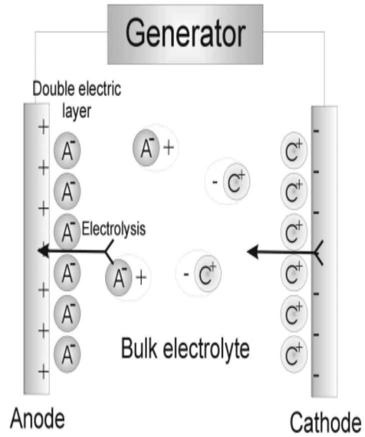


Fig 4: Conductometric Biosensor

B) Physical Biosensor:

Physical biosensor is a type of biosensor which detects the biological events following to the physical changes like temperature, fluorescence, refractive index, absorbance etc.

1) Piezoelectric Biosensor:-

The simplicity and low cost are main features of piezoelectric biosensor. Piezoelectric effect was discovered by famous Physicists Jacques Curie, Pierre Curie. Piezoelectricity means electric dipole. In piezoelectric biosensor quartz is mostly used due to good availability and reliability. Piezoelectric biosensor working is mainly based on the principle of recording the affinity of interaction. In piezoelectric biosensor inorganic anisotropic materials like aluminum phosphate, aluminum nitride, zinc oxide, crystalized topaz, crystalized tourmaline, barium titanate, gallium orthophosphate, lead titanate and quartz SiO2 are used[10-11]. Organic materials like Sodium potassium tartrate tetrahydrate known as Rochelle salt are used. Organic polymers like polyvinylidene fluoride are used.[11] Piezoelectric effect refers to the phenomenon, when material is physically stressed it produces voltage. This voltage is given to piezoelectric material by two electrodes, as the voltage alters it produces mechanical oscillation of crystal. Frequency of these oscillations are measured by putting the crystal on oscillation circuit. Frequency of this oscillation depends on mass bound the crystals[12].

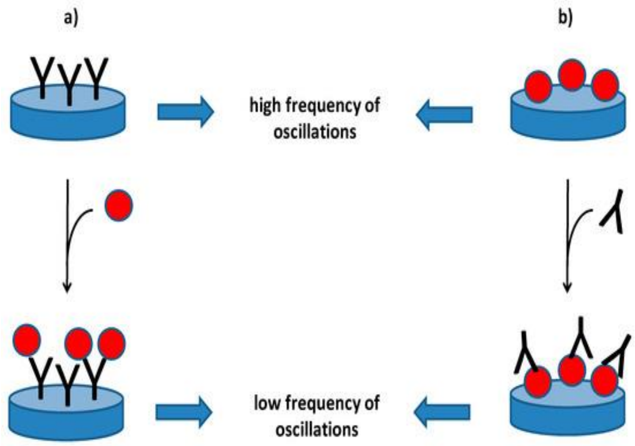


Fig 5: Piezoelectric Biosensor

2) Thermometric Biosensor:-

Thermal biosensor is based on the measurement of heat released or absorbed by the biochemical reaction. Recently, thermometric biosensor is used to purify contaminated water by removing organic contaminants from waste water. For purification of water COD parameter is used. COD means Chemical Oxygen Demand. To purify waste water strong oxidizing agents are used which oxidizes organic material present as contaminant. Number of oxidized oxygen in this reaction is called Chemical Oxygen Demand. During oxidation heat energy is produced which is measured by thermometric biosensor[13].

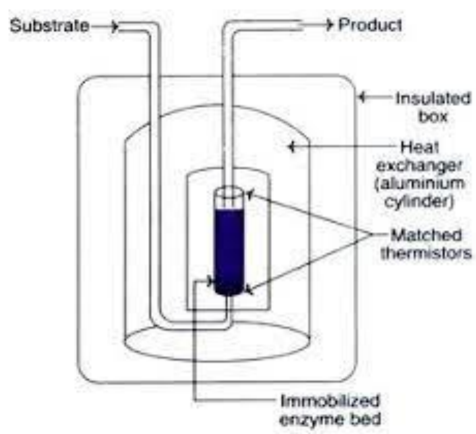


Fig 6: Thermometric Biosensor

C) Optical Biosensor:-

The development of sensitive, simple, low cost and easy to use biosensor is the demand of biomedical. Optical biosensor is also known as Bio –Optrode. Optrode word is the combination of optical and electrode which means fibre optic based analytical device which measures concentration of specific chemical or specific group of chemicals[14]. Optical biosensor contains biorecognition element incorporated into an optical transducer system. The signal generated by optical biosensor is directly proportional to concentration of an analyte. In optical biosensor biorecognition element is the main component, it is also known as biological sensing element which consists of enzyme, whole cell, tissue, antibodies, aptamers. The use fibre-optic sensors in biosensor make it more sensitive and it is mostly used in drug discovery and biomedicine. In optical biosensor dyes are combined with biorecognition element to transfer signal to optically detectable signal[13]. Fluorescent dyes are mostly used. Recently self fluorescent proteins are used which are obtained from marine organisms like jellyfish Aequorea victoria which give green fluorescent proteins. Hydrogels are simple substrate as compared to other substrates which are used for immobilization of DNA which having advantages like protection of DNA, controlled release and entrapment. For visual detection optical transparency of hydrogel is more effective. Optical biosensor shows the result by observing the changes in absorbance, fluorescence, refractive changes[15].

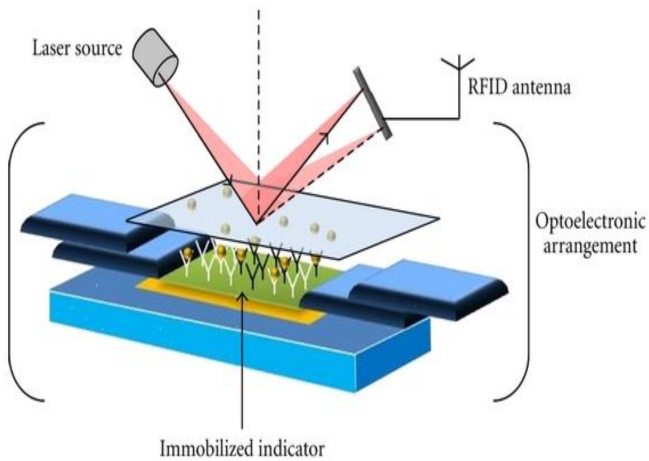


Fig 7: Optical Biosensor

Applications:

Biosensor devices include two main component such as biological element and physiochemical detector and the main function of this devices to detect analyte .so, the biosensors are widely applied in many fields namely pharmaceutical industries, medical field ,industrial applications, food industries ,environmental monitoring ,agriculture industry ,military etc. In recent years, these sensors have become very popular because they offer small size, low cost ,simple operation ,quick result ,and better stability, high sensitivity and specificity[16].

Pharmaceutical and medical field:

Potentiometric biosensors are developed with ion selective field effect transistors (ISFETs) for different applications such as chiral amine salt detection ,enzyme inhibitors of acetylcholamines esterase ,detection of pharmaceutical preparations such as lidocaine, procaine and tetracaine and detection of ionic surfactants like sodium dodecyl sulfate (SDS)and dodecyltrimethyl ammonium bromide. Fluorescent biosensors are used in drug discovery for the identification of drugs by high through put and high content screening approaches. Fluorescent biosensors are used for early detection of biomarkers in molecular and clinical diagnosis .they are used in detecting gene expression, protein localization and confirmation of fields such as signal transduction, transcription, cell cycle and apoptosis. Detection of cancer, viral infection, metastasis, inflammatory diseases, cardiovascular and neurodegenerative diseases is done by using this biosensor.

In medical field, the applications of biosensors are expanding rapidly .biosensors are mainly used for quantitative estimation of body fluids like glucose ,cholesterol ,urea, etc. Glucometer is a electrochemical based biosensors are widely used in clinical applications for diagnosis of diabetes mellitus, helps to precise control over blood glucose level. Glucometer usage at home accounts for 85% of world market. Biosensors are used to diagnose infectious diseases mainly urinary tract infection along with pathogen identification. Early detection of human interleukine-10 is carried out by using novel biosensor. Antibodies immobilized on gold as biosensor used for detection the presence the Human Papilloma Virus (HPV). Pregnancy kit used for detection of hCG in urine. Recently, biosensor used to specific virus SARS-Co-2 identification.

Industrial applications: Fermentation is a wide industrial operation used in alcohol, dairy and other products etc. In fermentation industries product quality and process safety are crucial .Biosensor used as monitoring fermentation products, biomass, enzyme and estimation of various ions And helps to control fermentation process.

Food industries:

Biosensors are used in food industry for food quality control .it is used to detect the odour, freshness, nutritional value of food and measures the carbohydrates ,amino acids ,alcohol , gases, etc. one of the popular food additive is a artificial sweeteners is detected with the help of biosensors .Due to artificial sweetener causing undesirable diseases such as dental caries , cardiovascular diseases ,obesity, and type 2 diabetes.

Environmental Monitoring:

Biosensors are very helpful in pollution control and environmental monitoring and also useful for monitoring pollutants ,chemical residues ,pesticides ,toxins or microbes in marine water ,rivers ,and reservoirs .Amperometric biosensor is a type of electrochemical biosensor used for detection of pesticides .Biochemical oxygen demand (BOD) biosensors used to detect biological molecule that contaminates water bodies and cause dangerous diseases that can lead to death.

Agriculture industries:

Biosensors are used to measure the level of pesticides, herbicides ,and heavy metals in the soil and ground water .To prevent contamination of soil disease at on early stage because of biological diagnosis of soil by using biosensor. Detection of amount of nitrate presence in soil is done by using nitrate biosensors .

Military: biosensors detect the toxic gases and chemical warfare agents[17].

Current research trends, future challenges and limitations of biosensor technology

Modern approaches for discovering new biosensors include integrated tactics utilising a variety of technologies, including electrochemical, electromechanical, fluorescencecum-optical-based biosensors, and genetically modified microorganisms. Some of these biosensors have incredibly promising futures in medicine and disease diagnosis. As a result of the need and necessity for using biosensors, bio-fabrication is now necessary in order to recognise cellular to whole animal activity with a detection limit of high precision for single molecules. The biosensors should therefore be designed to function in multiplex settings. In that case, sophisticated transducers are needed for both 2D and 3D detection in order to target and quantify small target analytes. With either contact-based patterning or non-contact-based patterning at various levels, several significant discoveries were achieved in this. The goal of the following stage of development should be to find more durable regenerative biosensors for long-term use. If this occurs, new diagnostic biosensors for therapeutics might be created, which would benefit patients and physicians in the long term by allowing for a more comprehensive understanding of disorders and treatment. Due to this, a biosensor based on fluorescence resonance energy transfer offered a great diagnostic method for determining how well imatinib treated chronic myeloid leukaemia. Typical examples of potential study methods in this area include the usage of aptamers, affibodies, peptide arrays, and molecularly imprinted polymers in the present day. Few promising compounds for innovative medicinal, antibacterial, and drug delivery also have little success. Electrochemical biosensors are discovered as viable analytical tools for pathogen detection of the avian influenza virus in the complicated matrices through invention in this area. A more recent study found potential uses for affinity-based biosensors in doping control analysis and sports medicine. For real-time, non-invasive screening of electrolytes and metabolites in body fluid as markers of a wearer's health status, a range of wearable electrochemical biosensors have recently been evaluated in detail. Assessing the quality of meat and fish using manufactured hypoxanthine biosensors is a fascinating application[18]. Utilizing a variety of biosensors such as electrochemical, nucleic acid, optical, and piezoelectric devices, development in biosensors for the detection of biological warfare agents such as bacteria, viruses, and toxins is frequently attempted. These devices will have enormous applications in military and health as well as defence and security. Combining nanomaterials, polymers, and various biosensor types will result in hybrid devices that can be used more effectively in the aforementioned applications. Additionally, the development of microbial biosensors using a synthetic biology approach will significantly contribute to the monitoring of the environment and the demand for energy. The authors of this study also emphasised the significance of using microbial fuel cells to create a way for treating water and to power environmental sensors. We focused on the many types of biosensors, their possible uses, and properties including analyte detection efficiency, analysis speed, mobility, cost, and customization[19].

Conclusion:

In conclusion, sensitivity, specificity, non-toxicity, and small molecules are the main factors that influence the development of biosensors. This study provides a quick overview of the biosensor concept, kinds, benefits, applications, and most recent developments. A recently created analytical tool called a biosensor is beneficial for diagnosing diseases as well as detecting different chemical reactions. This analysis examines every facet of the biosensor in light of recent developments. In conclusion, sensitivity, specificity, non-toxicity, tiny molecule detection, and cost-effectiveness are the main factors influencing the development of biosensors. Taking into account these traits will finally solve essential requirements as well as the issue of significant biosensor technological limits. New types of biosensors are produced as a result of some electrochemical sensor advancements combined with nanomaterials. In this light, the development of "electronic skin" in the form of printed electrochemical biosensors for physiological and security detection of chemical components is noteworthy. The key to the effective creation of potent biosensors for the modern era will be a better mix of biosensing, bio-fabrication, and synthetic biology approaches using either electrochemical, optical, or bio-electronic principles, or a combination of each.

References:

1. Darsanaki R, Azizzaddeh A, Nourbakhsh M, Golnaz Raeisi, Morteza Azizollahi Aliabadi, Biosensors: Functions and Applications, Journal of Biology and today's world, 2013, Volume 2(1): 53-61.
2. Sawant S, Shiralkar S., All about Biosensors-A Review, International Research Journal Of Engineering and Technology. 2022, 9(4): 2480-2484.
3. Tanu Bhardwaj, Review on Biosensor Technologies, A Review, International Journal Of Advanced Research In Engineering and Technology, 2015, 6(2): 36-62.
4. Price C.P. Point-of-care testing in diabetes mellitus. Clin. Chem. Lab. Med. 2003; 41: 1213–1219.
5. D'Costa E.J., Higgins I.J., Turner A.P. Quinoprotein glucose dehydrogenase and its application in an amperometric glucose sensor. 1986; 2:71–87.
6. C. Kokate, book of pharmaceutical biotechnology, nirali publication, second edition 2020: 3.4
7. Oxygen sensor (http://www.freepatentsonline.com/5827415.html).
8. Verma, N., and Bhardwaj, A. (2015). Biosensor technology for pesticides – a review. Appl. Biochem. Biotechnol. 175, 3093–3119. doi:10.1007/s12010-015- 1489-2.
9. Renault. N, Dzyadevych S. Conductometric Microbiosensors for Environmental Monitoring *Sensors* 2008, *8*(4), 2569-2588.

10. Shavanova K, Bakakina Y, Burkova I, Shtepliuk I, Viter R, Ubelis A, Beni V, Starodub N, Yakimova R, Khranovskyy V, Application of 2D non-graphene materials and 2D oxide nano structure for biosensing technology, MDPI, 2016, 4:1-23.
11. Pohanka M, Short Review The Piezoelectric Biosensors: Principles and Application, a review, International Journal of Electrochemical Science, Volume 12, 2017: 497-506.
12. Pohanka M, Overview of Piezoelectric Biosensors, Immunosensors and DNA Sensors and Their Applications, Materials 2018, 11(3), 443.
13. Vasuki S, Varsha V, Arul R., Abinaya S, Dharshini R, Sivarajasekar N. Thermal Biosensors and their Applications, American International Journal of Research in Science, Technology, Engineering & Mathematics, 2019: 262, 262-264.
14. Frances S Ligler and Charis A Rowe Taitt, Optical Biosensor Present and Future, Elsevier Publication, 2002, 1,5-12, 1.
15. C. Kokate, book of pharmaceutical biotechnology, Nirali publication, second edition 2020, 3.3.
16. Mehrotra P, Journal of oral biology and Craniofacial Research Res.2016 Aug, 6(2), 153-159.
17. Bagde V, Borkar D, Biosensor: Use in agriculture. 2, 10, 2013, 2-3.
18. Leif K. Mc Goldrick and Jan Halamek,Recent Advances in Noninvasive Biosensors for Forensics, Biometrics and Cybersecurity, October 2020. (22):1-15.
19. Zhou, Y., Chiu, C. W., and Liang, H. Interfacial structures and properties of organic materials for biosensors: an overview. Sensors (Basel). 2012. 12, 15036–15062.