Fiber optic sensors and their environmental applications

Juan Antonio Hernández Villanueva, Ruben Alejandro Sánchez Vázquez
Carlos Manuel García Lara

About the autors

School of Environmental Engineering, UNICACH . 1150 North West Bypass , Col. Lajas Maciel , Tuxtla Gutierrez , Chiapas, Mexico . Phone and Fax (961) 61 70 440 ext. 4270 . Email antonio.villanueva @ unicach.mx

Abstract

This investigation is an analysis of fiber optic sensors and their application in the environment, taking into account the quality of water , soil and air which are areas of interest because they are part of the environment in which life develops. A body of water, air or soil with high levels of contaminants are not apt for the life and development of a species . When it comes to measuring one or more physical parameters of the water or air, or to detect and quantify a substance, you need to use some kind of sensor to provide reliable data in order to implement solutions that mitigate the existing risks. The most commonly used sensors for these purposes are mechanical, electrochemical, and , for some parameters already in place, optical sensors. In the society in which we live, it is becoming increasingly necessary to develop small analytical devices that are inexpensive, portable , reliable , selective , easy to use and require only a few microliters of sample to determine a particular parameter.

Keywords : environment, physical, optical sensors.

Introduction

Pollution is defined by Henry and Heinke (1999 : 235-237) as "a biological undesirable change in the physical or chemical characteristics of the air, water or land which may adversely affect the health, survival or activities of humans or other living organisms ", and is a result of the improper use of resources in the production of goods and services and the consumerist way of life and our villous cultures (Bustos and Chacon . , 2009 , 164-181) .

Some of the main air pollutants that are known are: Nitrogen Oxides (NOX) , Sulfur Dioxide (SO2) , carbon monoxide (CO) , Carbon Dioxide or Carbon Dioxide (CO2) , ozone , Lead (Pb) , Mercury (Hg) and hydrocarbons (HC) . These contaminants can be primary or secondary. The primary contaminates originate directly from secondary sources and are formed in the atmosphere by combining the primary contaminates with normal atmospheric constituents (García and Martínez : 1978, 70-75) . There are various water pollutants , and in most cases they directly affect the health of human beings and their consequences can be severe :

Pathogens

They are those that cause disease . In general they are bacteria, viruses , protozoa and worms that enter the water from domestic sewage and animal wastes . In most developing countries, they are the main cause of diseases and deaths , including those of many children under five . An indicator of water quality for drinking or swimming is the number of coliform bacteria in a sample of 100 milliliters of water. The World Health Organization (WHO) recommends a count of 0 colonies of these bacteria per 100 milliliters of water. For drinking and swimming there is a maximum of 200 colonies per 100 milliliters of water. The sources of these agents may be excrement, both human and animal (Tyler : 1994, 27-39) .

Wastes that require oxygen

These are the wastes that can be decomposed by the presence of aerobic bacteria , which in turn are use oxygen to biodegrade waste. Very large populations of bacteria carried by these wastes can deplete the oxygen gas that is dissolved in water. Without this oxygen, fish and other life forms are killed . Pollution sources can be sewage, agricultural runoff, animal processing and papermaking (Tyler : 1994) .

Soluble inorganic chemicals in water

Such substances refer to acids, salts and compounds of toxic metals (such as mercury and lead) . High levels of these dissolved solids can turn water non-potable, harming fish and other aquatic life, and even affect agricultural life and accelerate corrosion of equipment that uses water. The main sources are from industries.

Inorganic plant nutrients

These nutrients are nitrates and phosphates that are soluble in water, which may lead to the overgrowth of algae and other aquatic plants which die and decompose, resulting in the depletion of oxygen found in water, fish kills and the death of other living things that depend on it . Excessive levels of nitrates in drinking water can reduce the oxygen carrying capacity of the blood and cause the death of babies, especially those under three months of age (Tyler : 1994) .

Organic chemicals

Organic chemicals that can pollute water are oil, gasoline , plastics, pesticides , solvents and detergents, among many other water-soluble and water-insoluble chemicals that threaten human health and damage aquatic life (Tyler : 1994) .

Sediment or suspended matter

These refer to insoluble particles in the soil and other solid materials , both organic and inorganic that are suspended in water. This material clouds the water , reduces the ability of some organisms to find food , reduces photosynthesis by aquatic plants , alters aquatic food webs and is a carrier of pesticides , bacteria and other harmful substances. The bottom sediment destroys the land or feed regions for fish, and clogs and fills lakes, ponds , bays and water channels. The primary source is terrestrial erosion (Tyler : 1994) .

Radioactive substances

Radioactive isotopes are water soluble substances capable of being amplified biologically in higher concentrations as they pass through the food chain . This radiation can cause birth defects and cancer, among other diseases. The main sources of these substances are mining, power plants and weapons production plants (Tyler : 1994) .

It is considered that 58.4 % of surface water is contaminated, with few areas of the country that have good water quality (Alcocer : 1998, 127-129) . It is also estimated that between 75 and 90 % of hazardous waste (toxic, reactive , explosives , flammable or infectious waste) is handled without adequate systems of environmental control , creating serious pollution processes in agricultural, industrial and urban areas (Diaz, et al : 1998, 104-115) . In this scenario it is important to consider that reaching a kind of feasible development in both economic and ecological terms does not only depend on the implementation of new technology and regulation measures on the use of resources.

Sustainability implies in itself the generation of new forms of social life , ie , new norms, values and virtues that enable building a different social - environmental relationship. It becomes indispensable , then, to know how and under what circumstances environmental values are taught within a society (Durand : 2004, 511-530) . The importance of environmental quality is an unquestionable fact in today 's society, especially in the social-environmental relationship , and thus a quick measurement of contamination is necessary to maintain control of the environment. This is where biosensors play a role . The term biosensor is applied to a analytical system engaging a sensitive biological element associated with a transduction system , which can detect and measure quickly , proportionally , accurately and sensitively a signal produced by the interaction of the biological element and the substance of interest (Castro- Ortiz, et al : 2007, 35-45) .

Environmental biosensors , according to the type of technique used, can be classified in bioassays and biosensors . Bioassays were the first biological tool to be applied to the environmental field. Basically they are methods employing various living materials to estimate the potential toxicity of a substance or a contaminated matrix. A bioassay is generally defined as an experiment aimed at investigating the role of a substance in a biological , ecological or evolutionary context , using organisms or living systems (Mozaz , et al : 2005, 291-297) . The term biosensor is applied to an analytical system engaging a sensitive element associated with a biological transduction system which can detect and measure rapidly , proportionally , accurately a sensitive signal produced by the interaction of the biological element and substance of interest (Castro- Ortiz, et al : 2007) .

In the past 10 years biosensors have been integrated with pollution control programs , implementing them in environmental security systems in two ways:

1. Monitoring methods capable of predicting the possible danger of biological effects such as toxicity, allowing the measurement of a lot of pollutants in short periods of time.

2. Methods of screening used to detect the presence of a contaminating compound.

The sensors are alternatives to conventional analysis tools. The arrangement of a fiber optic sensor based on the sol- gel method has two important characteristics:

1. On site, real time analysis. This translates into a result of increased reliability , since we avoid that the substance loses its original characteristics due to its transfer. Early detection allows us to take measures for prevention and mitigation.

2. The sol-gel is an inert material-in other words it presents resistance to very hostile environments that many polymer based sensors don't have (Valcárcel and Luque de Castro, 1994 , 32-55) .

Definition of fiber optic

An optical fiber is a dielectric medium that carries physical information in the form of light , that is, guided electromagnetic waves parallel to the fiber axis . It consists of a core which permits the propagation of light , an optical cover or coating that allows for the propagating mechanism, and one or more coatings of mechanical protection (Fig. 1) (Vazquez : 2011 , 163 - 188) .

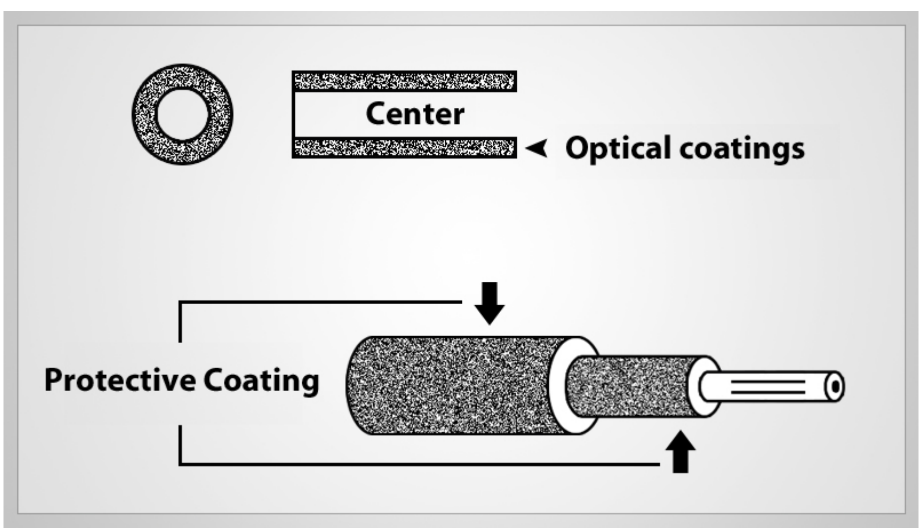

Figure 1 . Representation of an optical fiber (Vázquez , 2011)

The fibers are made from glass , consisting of silicon or a silicate (SiO_2) . The center must have an index of refraction greater than the coating , so that there is total internal reflection. Doped oxides such as GeO_2 , B_2O_3 and P_2O_5 are added to silicon to obtain the difference between the refractive indices (Vazquez : 2011)

Fiber optic sensors are known in the scientific community as optodes , first mentioned by German researchers Opitz and Lübber, referring to an optical system for measuring CO_2 (Wolfbeis and Bernhard : 2006, 95-111) . Some characteristic properties of the optodes (Marazuela : 1997 , 103-109) in the environment are :

- They do not require a reference signal. Unlike potentiometric and amperometric electrodes that measure the absolute potential deference , optodes do not need a reference signal .

- The possibility to build remote sensing. The use of low loss optical fibers as light guides enables measurement over long distances , providing access to sensor measurement locations . Great depths in lakes or media exposed to ionizing radiation or electromagnetic interference , unlike conventional electrical sensors , is not a problem for these systems since the distance between the terminal and the sensitive transducer can be adapted to the measurement conditions without entailing loss of information.

- Multi parameter measurement. Due to the large bandwidth of optical fibers, it is possible to transmit more information than electrical cables. That is, the optical signals that are caused by the presence of different data in the sample may differ from each other in wavelength, phase, polarization or intensity modulation; therefore a multi parameter sensor can have a multiplex of these signals.

- Sensitive terminals are easily interchangeable. The multi parameter analysis can also be performed by exchanging specific sensitive terminals whose indicators are based on the same measuring principle which allow the use of a single instrumental device. This advantage of fiber optic chemical sensors are particularly useful in clinical chemistry , because it facilitates the sterilization of the terminals and enables the use of disposable sensors (Bustamante , 2001 , 55-59) .

Propagation

Light waves are referred by their wavelength , which is related to the frequency by the expression $\lambda = c / f$ where λ is the wavelength , c is the speed of light and f is frequency.

Since light is a form of an electromagnetic wave, its properties must be described from the Maxwell equations. The rigorous method of calculating the intensity and phase of a light wave implies the use these equations . However, because the wavelength of the electromagnetic waves (infrared and visible) that are propagated is small , the study of the propagation inside the fiber can be performed with the simplified model of light rays and laws of geometrical optics (López- Higuera : 2002, 89-98) .

Thus, the study of the arrival of the wave or light to the interface between two media with different refractive indices beam can be performed in two ways:

A. As an optical wave, which should be resolved with the wave equation , which imposes the boundary conditions .

B. As a light beam using Snell's law and total reflection (Wolfbeis and Bernhard , 2006).

General aspects of optical fiber

With the development of fiber optics in the late '60s, practical optical communication systems were obtained. Quickly these technologies developed for optical communications , were joined to optical detection technologies ,and allowed the introduction of elements of optical fibers as waveguides for optical sensors . Since then they have shown steady progress and have greatly developed (López- Higuera , 2002). The application of optical fibers to carry the signal so it operates as an active element of the sensor (transducer) makes it possible to miniaturize the optical system (making them suitable for compact, portable field use) , increasing its sensitivity and making the use of more powerful sources of radiation appropriate . The low cost technology available is crucial for the success of optical sensor systems that can take advantage of fiber technology and manufacturing methods produced for telecommunications devices (Alois : 2001, 203-209) .

The main effort of researchers has been made to produce a set of techniques based on optical fiber that can be used for a wide variety of purposes , providing a good basis for a technology that can effectively complement conventional methods. This is the key to success of optical fiber sensors : taking measurements in difficult situations for specific environments where the use of conventional sensors is not possible.

Advantages and disadvantages of fiber optics

The main advantages of fiber optic technology makes available to researchers for use in sensors include:

- Cheap telecommunication fibers .
- Infrared sources available: LED 's, laser diodes. Possibility of using laser fibers.
- Wide range of lasers which can be coupled to reasonably effectively fibers .
- Wide range of detectors: pin devices, avalanche photodiodes , etc. .
- Availability of new integrated optical or optical systems (Grattan : 1997, 109-119) .

However , a number of technological problems exist that make the ideal situation is not so easily appliable:

- Telecommunication fibers are sometimes inappropriate for use as sensors: they need larger diameters / numerical apertures , the exotic fibers are expensive for small production runs , large diameter fibers are expensive and inflexible .

- Losses due to the bends in fiber -based sensors affect intensity measurements .

- Laser sources are often difficult to couple with optical fibers : many laser diodes or LEDs have wide angles of emission and provide a limited laser power in a useful wavelength .

- Many laser sources in the visible or the infrared means are large, expensive and unsuitable for the use and coupling of fibers.

- Telecommunications fibers have a limited temperature range : typically the upper limit is at 100-150 ° C while many applications require temperatures greater than 200 ° C.

- The methods of mechanical coupling of extrinsic sensors can be complex or unreliable , especially with environmental changes .

- Doped fibers are expensive and limited in available dopants, which are governed by the telecommunications needs (Er , Nd) .

- Laser fibers, promising as sources, are expensive and are primarily infrared or red , or require complex frequency doubling equipment.

- There is a need for hand assembly of the sensors : a high cost is associated with many of them.

- Training for staff is necessary in order to become familiar with new techniques (: Grattan 1997) is necessary .

As a result of all this, when developing the sensors it is necessary to achieve a number of practical commitments in the specifications, materials , response, sensor size and robustness, etc. . This can be determined in order to define what an ideal sensor fiber must be. The ideal specifications will only be practical for certain applications. However it is worthwhile for the particular case of fiber optic sensors designed to explore the environment, while trying to get these ideals even though only some can be used (Grattan : 1997) . Therefore, to take full advantage of the benefits by minimizing the drawbacks a sensor should:

- Operate in the infrared or red to take advantage of the simplicity and low cost of sources and detectors.
- Intrinsically operate to prevent couplers and not base on intensity measures to avoid losses for coupling or curvature .
- Do not show problems with power levels : sufficient photon for a detection with low noise.
- Use telecom fiber and minimize the need for the number of couplers .
- Operate in a temperature range T < 150 ° C.
- Be insensitive to any other parameter as much as possible .
- Be cheap and easy to produce automatically .

The potential of fiber optic sensors is significant. It has been found that as the cost of key components decreases and the number of cheaper components is extended , the potential for further market and quality of components increased (Herrera : 2005, 141-153) .

Fiber types

Depending on the light signal propagating within the fiber , they are classified into the following groups :

1. multimode
2. single mode

In a single mode fiber , light can have a unique path through the core , measuring about 10 microns in diameter . Multimode fibers have cores between 50 and 1000 microns. Mono mode fibers are more effective for long distances , but the small diameter of the core requires a high degree of precision in its manufacture , splicing and fiber termination (Krohn : 1988 , 53-77) .

The optical fiber is also classified according to the refractive index, classified as two types:

a. Step index
b . Gradual Index

In the graded index fibers , the refractive index is lower in the vicinity of the coating than on the fiber axis . The waves propagate slightly slower in the vicinity of the core shaft near the coating .

Considering the fiber material , they can be classified as:

a. Fiberglass
b. Plastic fibers

These latter are used for communication over very short distances. Often used to interconnect equipment in the same building , connecting digital audio equipment and small sized computer networks.

Within the first two general classifications (type of propagation and refractive index) , we have three basic types of fiber :

a. Multimode step-index fiber
b . Graded index multimode fiber
c . Single mode fiber

Multimode fibers are typically used in the first and second windows, and single mode in the second and third windows (Krohn : 1988) .

Multimode step-index fiber

Guiding the light signal is caused by the total reflection at the interface between the core and cladding . The refractive index has a defined profile by the following expression :

$n = n (1 + \Delta)$ (where Δ increase the refractive index between the core and cladding)

In this type of fiber the numerical aperture , NA , can be approximated by the expression : NA = 2Δ . NA typical values are between 0.2 and 0.5 .

The incidental signals with an angle whose sine is less than the numerical aperture cause the appearance of many modes (or said in a more intuitively manner, a multitude of rays and angles of reflection) propagating through the interior of the fiber (Figures 2 and 3) . This is why we use the term multimode to describe the type of fiber .

The core of these fibers have a diameter between 50 to 1000 microns . This large nucleus involves several propagating modes . The different paths give a place for the modal dispersion , in other words the temporal spread of light as it travels through the fiber. Dispersion is a mechanism that limits the bandwidth or the amount of information that the fiber is capable of transporting .

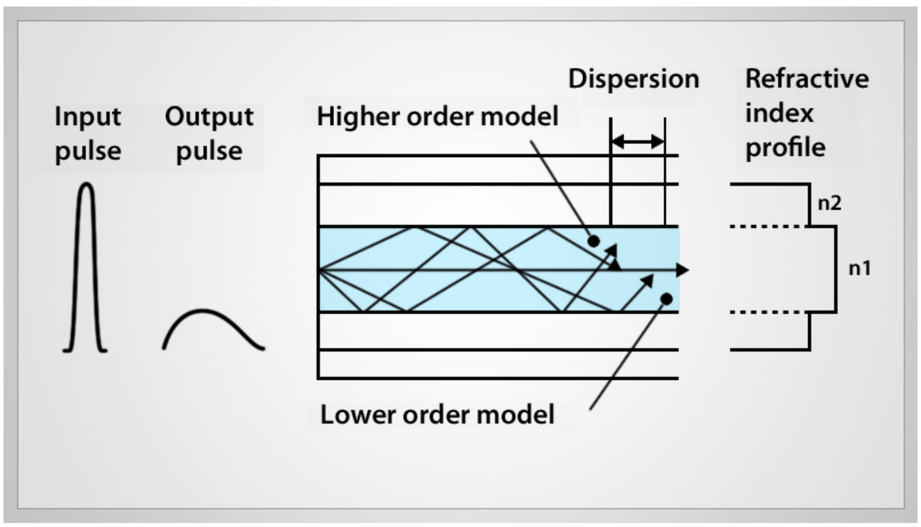

Figure 2 . Multimode fiber (Krohn : 1988) .

These fibers can be further classified according to their composition :

1. Glass / Glass: glass shell and core .
2. Plastic / Glass: plastic casing and glass core .
3. Plastics / Plastic: plastic shell and core .

Such fibers are the links used in short distances up to 1 km. and its most important application is in local networks.

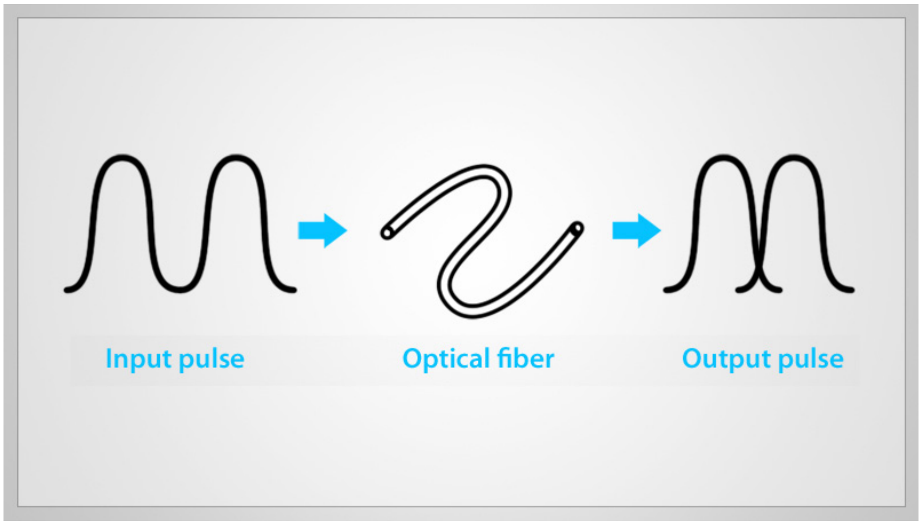

Figure 3 . Dispersion (Krohn : 1988)

Graded index multimode fiber

In this case the change of refractive index in the interior of fiber is gradual , resulting in a wave propagation of the light beam (Figure 4) . The graded index fibers engage in the coupling efficiency for greater bandwidth. It does this by giving the core a non-uniform refractive index throughout its profile.

The variation of the refractive index profile of the fiber results in that the light propagates according to a curved path rather than in straight sections as in step-index fibers . The greater distance of the beam is offset by the higher velocity of propagation (V = c / n) in the outer region of the core .

In these fibers the acceptance angle depends on the distance to the core axis , maximum at the center and zero at the border with the coating . However, the numerical aperture (NA) of the graded index fibers is defined in the same way as in step-index :

NA = (2 n1 - n2 2) 1/2

The NA has a typical value of 0.2 for these fibers.

Most graded index fibers have a core diameter of 50 microns and a cladding diameter of 125 microns .

These fibers cause fewer modes of propagation than step index , reducing the dispersion , thereby increasing bandwidth . These fibers are used up to distances of 10 km.

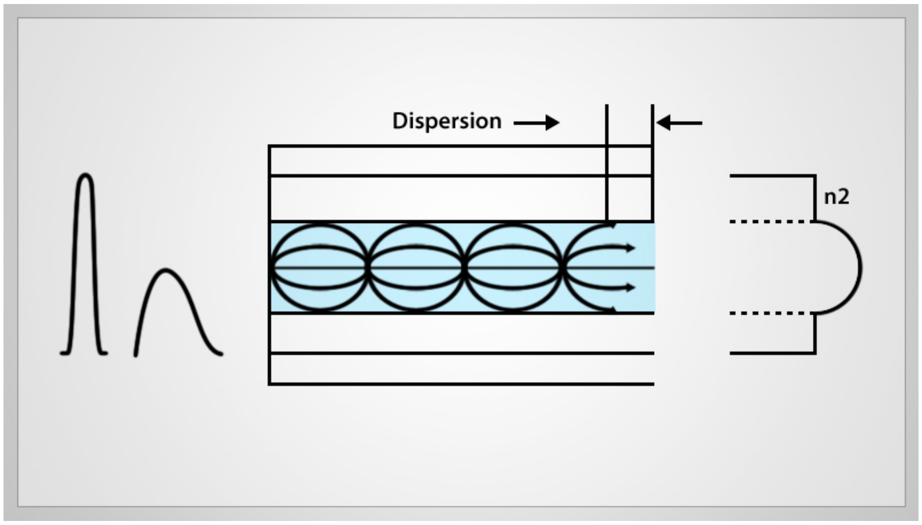

Figure 4 . Graded index multimode fiber (Krohn : 1988) .

Single mode fibers

When very large band widths are required single mode fibers are used . These fibers , in its simplest construction , are equal to the multimode step index , except that the core diameter is very small (5-12 microns) , being able to propagate a single mode.

The modal dispersion is very low, only about tens of pi - cosegundos (10-12 seconds) per kilometer , which bandwidths are exceptional and low loss , being suitable for long-distance or high-speed communications (Krohn : 1988) .

It is the simplest conceptual case , as it is a step-index fiber but with a core diameter so small 15 16

(less than 10 microns) that it only allows the propagation of one mode, the basic mode(Figure 5) .

This type of fiber is what allows better performance and is used in long-distance links . These fibers have ,however, some disadvantages such as increased difficulty injecting the optical signal to the fiber

(typical numerical aperture of 0.1 @ angle of incidence of 12 °) , increased sensitivity to mechanical error , abuse, bad splices , etc . The difficulty of signal injection is resolved used laser light sources (Krohn : 1988) .

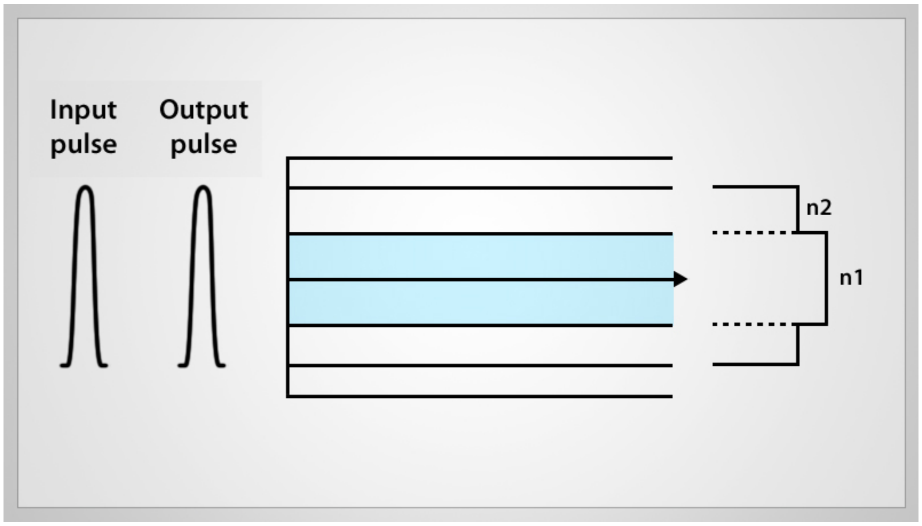

Figure 5 . Singlemode fiber (Krohn : 1988) .

Fiber optic sensors for monitoring environmental parameters

Applications of fiber optic sensors corresponds to the tasks of environmental monitoring, industrial process control , and biomedicine . They have successfully developed optical sensors for monitoring of molecular oxygen , carbon dioxide , pH , iron , hydrogen sulfide , alcohols , humidity, temperature , detergents , oils , pesticides, glucose, acetyl choline, and cholesterol , in addition to the union of the optical sensors with biological molecules (enzymes , antibodies, DNA) biosensors , which are used in different areas such as medical diagnostics, biological applications (detection of bacteria) , and the monitoring of water and air (Espinoza et are built to : 2007, 797-859) .

A clear demand exists for screening methods that operate in-situ and which have the potential as environmental applications of sensors in general and fiber optic sensors. They are :

- Environmental analysis such as media points

- Continual target monitoring.
- Early warning systems .
- Environmental control systems .
- Environmental protection systems .

You can sort environmental sensing applications according to the area to be monitored: home sensors , industrial monitoring inside of buildings, outdoor sensors and in space , marine sensors or for water purity (López- Higuera , 2002).

The appropriate strategy for environmental monitoring is strongly dependent on the analytic to be detected, the medium containing the substance of interest , the accessibility of the area to be analyzed, the danger of the surrounding environment , the desired quality of the information obtained , and the current legislation. Every step from identifying a problem, to cleaning up pollution and the potential for subsequent monitoring require different analysis techniques that highlight potential areas of application of sensors in environmental monitoring .

When a contaminated area is identified, an extensive characterization of the location is essential which includes the nature and level of contamination . They are necessary analysis techniques and diagnostic tools to identify unknown contaminants and expected. The analysis of the obtained data will give us the contaminants specifications (Herrera : 2005) .

These measures typically require making many discrete samples to be analyzed in batches for the presence or absence of contaminants.

Demand for exploring the countryside and having portable devices emphasizes the use of miniaturized laboratory methods applicable in the field, as well as sensors capable of providing in- situ analysis. This latter feature is a valuable advantage when considering the determination of volatile organic compounds , especially as the in-situ analysis without sampling procedures there are errors due the evaporation of the analytic or changes in the medium can be minimized.

A constant monitoring of pollutants is critical in order to continuously adapt such a process to reduce costs by minimizing remediation efforts if desired cleanliness level (Herrera , 2005) is reached.

Depending on the legislative means, treatment or further monitoring may be required. In that case, in- situ sensors that act as thresholds alarm devices would be highly effective in time and cost compared with the classical laboratory analysis. The robustness , reliability and being inert to electromagnetic influences makes the fiber optic sensors ideal candidates for such tasks. Another area of interest for analyzing systems which operate continuously is the long-term monitoring of environmental parameters such as water pollution caused by large quantities of agricultural fertilizers , herbicide and pesticide input or industrial wastewater (Herrera , 2005).

Sensors are claimed to determine parameters such as oxygen, pH , carbon dioxide , ammonia , nitrates, PAH , etc. . Monitoring devices facilitates quality control of water and adjustment of the thresholds of environmental alert in case of accident . The points of application for such systems are continuous monitoring stations in rivers, estuaries and shallow coastal waters . Due to the versatility and flexibility of fiber optic sensors, they represent an attractive alternative to the electro chemical measures (Herrera , 2005).

Optodes applied to water analysis

Between 1984 and 1986 , the EPA (Environmental Protection Agency) published a series of reports in which the assessment and improvement of water quality in order to protect public health and the ecosystem are included . The highlights of these reports were tightening measures adopted by each State on the quality of water and the creation of an organization to ensure strict compliance with the standards established by the EPA (Bustamante : 2001) .

In 1994 , within the Fourth Framework Programme for R & D of the European Union /Sub-Program for Environment, two priority objectives were established: (a) identify and assess the effects of human activity on the ecosystem and (b) contribute to the need for observation, environmental monitoring and research technology development, including the methodologies and technologies for monitoring , prevention and management of natural hazards . On this last point , EU places particular emphasis on the development of sensors for all applications where conventional systems are limited by sensitivity, selectivity , accuracy, reliability and / or cost, as well as in industrial processes that include cleaner production . At present, and until 2002 , the V Framework Programme (1999) is in effect which re- emphasizes the need to control the pollution of water resources through water and analytical systems at monitoring points or for accidental pollution sources (Bustamante : 2001) .

Traditionally , control of water quality was carried out by the essential samplers and their subsequent transfer to laboratories, where thanks to current analytical techniques, such as atomic absorption spectroscopy (AAS) gas chromatography (GC) , liquid chromatography (HPLC) and mass spectrometry (MS) , all kinds of pollutants are detected and quantified.

The main analytics for monitoring in water are : pH , O2 , CO2, organic pollutants, heavy metals and radioactive particles .

The remote monitoring of contaminants in groundwater is a field where the use of fiber optics offers great advantages , as is the ability to run fiber to the point of interest even at great depths. The first luminescent pH sensor was developed by Saariet al. (1982) , the reactive phase sensor fluoresceinamida trapped in an acrylamide polymer , covalently immobilized on the end of an optical fiber. The main advantages of this optode are short response time by not having a membrane and wide working range (pH 2-9) by having two constants of successive acidity indicator. Its main drawback is its poor accuracy (Perez 2001 , 130-140) .

Whenever the concentration of a substance in water is legislated, the optimization of a measuring method is necessary, which usually appears along with the allowable limits of concentration of this type. Generally, laboratory methods allow the measurement of a large number of analytics with a lower cost than would use fiber optic sensors , which are usually developed for the measurement of a single parámeter.

In order for a fiber optic sensor to replace the traditional methods of measurement , it is necessary to introduce improvements in optodes for various analytical parameters such as sensitivity, selectivity , accuracy and response time . They must be competitive in terms of market costs in reference to currently implemented methods , which can be achieved when multiparamete optodes are manufactured.

Conclusions

The study of the development of fiber optic sensors is of great importance because the use of these sensors is continuous and in situ to monitor the concentrations of different analytics at the environmental level . Using fiber optics in conjunction with some means such as dopants, opens a new field of research in which the use of chemical methods for the analysis of some environmental physical parameters that contaminants provoke making greater reference to the analysis of water and soil .

The use of these chemicals are at times harmful aggressive to the ecosystems , hence the importance of using a fiber optic sensor to provide reliable data to apply solutions to mitigate the risks that exist .

Bibliography

1. **Alcocer** Durand, J. (1998) . *Pollution of inland waters. Habitat destruction.* Coordinated by G. Cortina and M. Toledo Leal Paez. Mexico : UNAM - PUMA. Pp. 127-129 .

2. **AloisT** . (2001) . *Modern sensors handbook*.Sf , edited by PavelRipka.Pp . 203-209 .

3. **Bustamante** Alvarez N. (2001) . *PH and temperature sensors for environmental monitoring detergents with a prototype that uses fiber optics and luminescence phase resolution* . Doctoral Dissertation. Complutence University of Madrid. Pp. 55-59 .

4. **Bustos** Flores, **C.** Chacón and **Parra** , G. B. (2009) . *Sustainable development and Agenda 21* . Telos, Universidad Rafael Belloso Chacin , Vol.11, No.2 , Venezuela , p. 164-181 .

5. **Castro- Ortiz**. (2007) . *State of the art and prospects of the use of environmental biosensors in Mexico* . Rev. Int Contam. Ambient. 23 (1) 35-45 .

6. **Diaz** Barriga , F. , G. **Pedraza** , R. **Reyes**, L. **Carrizales** and L. **Yanez.** (1998) . *Hazardous waste contamination* . *Habitat destruction.* Coordinated by G. Cortina and M. Toledo Leal Paez. Mexico : UNAM - PUMA. Pp. 104-115 .

7. **Durand** P. V. and S. **Durand** (2004) . *Values and attitudes about environmental pollution in Mexico* . Reflections around Postmaterialism , Mexican Journal of Sociology, UNAM , 63 (3): 511-530 .

8. **Espinoza** Bosch , A. J. **Sánchez** Ruíz , F. **Sanchez** Rojas and C. **Bosch** Ojeda. (2007) . *Recent Development in Optical Fiber Biosensors*. Sensors , 7, pp . 797-859 .

9. **García** , C. and **Martinez** , M. (1978) . *Technical Safety and Industrial Hygiene* . Editorial Mapfre, SA Spain . Pp. 70-75 .

10. **Grattan**K.T.V . (1997) . *Principles of optical fiber sensing applications for water industry , Measurement 20* (2) , 109-119 .

11. **Henry** , G. and **Heinke** , W. (1999) . *Environmental Engineering.* Prentice Hall, Mexico , pp . 235-237 .

12. N. **Díaz** Herrera (2005) . *Development of fiber optic sensors for in situ physical parameters of the water environment control.* PhD Thesis , University of Madrid Complutence . Pp. 141-153 .

13. **Krohn**D.A . (1988) . *Fiber Optics Sensor, Fundamentals and aplications Instruments.*Society of America.Capítulo 2 . pp. 53-77

14. JM **López- Higuera** (2002) . *Handbook of optical fiber sensing technology*.John Wiley & Sons LTD. Pp. 89-98