Multifunctional Fiber Optic Passive Glass Sensor:  
Determination of Various Environmental Parameters at 303.15K Temperature Using 660nm Light Source  
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Abstract: Detection of various environmental parameters is a field of growing interest which finds applications in diverse areas ranging from civilian uses to the chemical, food, medical, military, pharmaceutical industries, etc. Optical fiber passive sensors offers new and wide range of interesting characteristics which overcame most of the disadvantages encountered with conventional sensors available over five decades ago. The optical fibers with their advantages such as light in weight, low attenuation, passive in nature, possibility of multiplexing, immune to EMI & RFI, inertness to chemicals, applications in OTDR (optical time domain reflectometry) and their minimum invasiveness among others makes them to be the best alternative to the traditional sensors. These are suitable alternative to electronic sensors especially in electrical noisy environment. In the present paper a method of measuring various environmental analytes such as refractive index, density, viscosity, ultrasonic velocity, molar volume, molar refraction, dielectric constant, acoustic impedance, adiabatic compressibility, viscous relaxation time, intermolecular free length, Gibb’s free energy, free volume, internal pressure, effective mass, concentration and molar fraction and their mechanism behind it has been studied using chemical mixtures with the combination of methanol and toluene. The sensor is calibrated as a multifunctional device at the temperature of 303.15K using 660nm light source.

1. Introduction

The progress of the optical fiber sensor technology was related to the development of optical fiber was developed in 1950’s and with the advent of modern LASER’s in 1960’s. The transmission of optical signals was demonstrated in 1963 with extremely low losses [1]. The optical fiber technology could make the copper cable data networks obsolete by replacing the electronic systems, which was much more established. The mechanical sensors are the other kind of competing sensors which shown new developments with mature technology [2]. In the technology of telecommunication the fiber optic sensors had experienced great advancement making them as an option to implement in comparison with other technologies [3-4]. Fiber optic sensors offers many advantages such as small in size, light in weight, cheap in cost, sensing of parameter from remote, immune to electromagnetic interference (EMI) and radio frequency interference (RFI), multiplexing of several sensors for simultaneous measurement of various parameters, monitoring of parameters online, passive in nature, sensing of various parameters distributed over a region and so on and so forth. Optical fibers immunity to electromagnetic interference (EMI) they can be used in electrical industry [5]. Volatile organic compounds are commonly used in food processing, beverages, household products, paints and waxes, meat and fish products, etc., which get evaporated normally at room temperatures and can result sever health problems when breathed [6-7]. The extrinsic optical fiber sensors effectively can be used for sensing, analysis and monitoring of chemicals which are volatile in nature. Optical fiber nerve systems also known as distributed sensors, can be employed to interrogate several parameters spreading over a distance [8]. Optical time domain reflectometry can be applied in commercial systems enabling one to know the specific location and
exact concentration with a high resolution of parameter [9]. The dissolved gases in blood and in liquids can be measured using optical fiber sensors apart from their food processing control [10]. Depending upon the parameter to be measure several geometrical approaches have been used in the architecture of the various optical fiber sensors [11-12]. Optical fiber sensors can be broadly classified into two categories, i.e., intrinsic and extrinsic depending upon the interaction of light with measurand weather inside the fiber or outside the fiber respectively [13-15].

2. Experimental details

Based on parameter to be measured several geometries of optical sensors can be designed to measure various environmental parameters. In the present study an extrinsic optical fiber sensor has been developed using a borasilicate uniform solid glass rod as a sensing probe. The experimental work has been carried out in four phases in a sequential order.

Construction of experimental setup: The apparatus for main experimental setup consist of a light source of wavelength 660nm, a bench mark optical power meter, two PCS optical fibers of 200/230μm diameter of 50cm each in length and a uniformed U-shaped glass rod of thickness 0.5mm, width between two prongs 5mm, radius of the curvature 2.5mm, depth of the curvature 2.5mm, total height of the glass rod 40mm.

In the assembly of the sensor system the first end of the input fiber is connected to the source using SMA connector. The second end of the input fiber is connected to the first end of the glass rod using a glass to glass connecting index matching glue available in the market. The second end of the glass rod is connected to the first end of the output fiber. The second end of the output fiber is connected to the optical power meter using another SMA connector.

Determination of refractive index, density, viscosity, ultrasonic velocity: An arrangement consists of two burettes fixed to the stands at certain height is used to take the liquids in different proportions to prepare liquid mixtures from toluene and methanol.

Refractive Index (n): An Atago (Japan) make automatic digital refractometer of model number RX-7000i of refractive index range from 1.29980 to 1.71500, temperature range from 5.00°C to 75°C accuracy of refractive index 0.00001 and accuracy of temperature 0.01°C is used to measure the refractive indices of different mixtures at temperature of 303.15K.

Density (ρ) (kg.m⁻³): Using a 20ml specific gravity bottle the densities of all the mixtures were measured by relative measurement method with an accuracy of ±0.1kg.m⁻³. The experimental mixture in the specific gravity bottle was immersed in the temperature control water bath and an electronic digital balance (model no. SHIMADZU AX-200, Kyoto, Japan) was used to measure the weight of the sample with an accuracy of ±0.1mg.

\[ \rho_2 = \left( \frac{w_2}{w_1} \right) \rho_1 \]

Where: \( \rho_1 \) & \( \rho_2 \) are densities of distilled water and chemical solutions
\( w_1 \) & \( w_2 \) are weights of distilled water and chemical solutions
Viscosity ($\eta$) (N.m.s$^{-2}$): Viscosity of the liquid mixtures is determined using a Oswald viscometer of accuracy of $\pm 0.001$ N.s.m$^{-2}$. A digital racer stop watch with accuracy of $\pm 0.1$ sec was used to determine the time of flow of the liquid.

$$\eta_2 = \eta_1 \left( \frac{t_2}{t_1} \right) \left( \frac{\rho_2}{\rho_1} \right)$$

Where: $\eta_1$ & $\eta_2$ are viscosities of distilled water and chemical solution $\rho_1$ & $\rho_2$ are densities of distilled water and chemical solution $w_1$ & $w_2$ are weights of distilled water and chemical solution

Ultrasonic Velocity (U) (m.s$^{-1}$): Ultrasonic interferometer of model no M-84S (Mittal enterprises, New Delhi, India), Operating frequency Range: 1–12 MHz, Temperature range: −10°C to 85°C, Accuracy of Temperature: $\pm 0.1$°C, Accuracy of ultrasonic velocity: $\pm 0.03\%$ m.s$^{-1}$ is used to determine the ultrasonic wave velocity through the liquid mixtures at 2MHz frequency.

Determination of optical output power: Using the main experimental setup, initially the power is launched from the source and the output power is recorded from the optical power meter, when air is surrounding the U-shaped glass rod. Immersing the U-shaped glass rod into the first liquid mixture, the power reaching the light detector is noted down maintaining the height of the liquid as 1cm. Taking the other liquid mixtures of different proportions and immersing the U-shaped glass rod into each mixture one by one the output powers are noted at each time and are recorded. The procedure is repeated maintaining the height of liquid mixture as 2cm and 3cm.

Determination of other optical parameters: The experimental process helps to determine the other optical parameters of the liquids such as molar volume, molar refraction, dielectric constant, acoustic impedance, adiabatic compressibility, viscous relaxation time, intermolecular free length, Gibb’s free energy, free volume, internal pressure, effective mass, concentration and mole fraction and their relationships with output power has been established. The excess values of all the above parameters except mole fraction were related with output power. The relationships with original parameters with excess parameters have been derived and determined.

3. RESULTS AND DISCUSSION

From the recorded data the relationships between various parameters have been determined and the results are represented graphically. The variation of the output power with respect to refractive index, density, viscosity, ultrasonic velocities have been represented graphically [fig. 3-6].
The influence of parameters of the chemical mixtures such as molar volume, molar refraction, dielectric constant, acoustic impedance, adiabatic compressibility, viscous relaxation time, intermolecular free length, Gibb’s free energy, free volume, internal pressure, effective mass, concentration and mole fraction on output power have been plotted graphically [fig.7-20].

Fig. 7: Relation between Gibb’s free energy Vs Output power for methanol mixed in toluene

Fig. 8: Relation between Absorption coefficient Vs Output power for methanol mixed in toluene

Fig. 9: Relation between Intermolecular free length Vs Output power for methanol mixed in toluene

Fig. 10: Relation between Viscous relaxation time Vs Output power for methanol mixed in toluene

Fig. 11: Relation between Molar Refraction Vs Output power for methanol mixed in toluene

Fig. 12: Relation between Molar Volume Vs Output power for methanol mixed in toluene

Fig. 13: Relation between Dielectric constant Vs Output power for methanol mixed in toluene

Fig. 14: Relation between Effective Mass Vs Output power for methanol mixed in toluene

Fig. 15: Relation between Mole fraction Vs Output power for methanol mixed in toluene

Fig. 16: Relation between Concentration Vs Output power for methanol mixed in toluene
The excess parameters which arise out of their mixing with other liquids have been determined and the results have been shown graphically [fig.21-35].
Fig. 27: Relation between Excess Free Volume Vs Output Power for methanol mixed in toluene

Fig. 28: Relation between Excess Ultrasonic Velocity Vs Output Power for methanol mixed in toluene

Fig. 29: Relation between Excess Gibb's Free Energy Vs Output Power for methanol mixed in toluene

Fig. 30: Relation between Excess Acoustic Impedance Vs Output Power for methanol mixed in toluene

Fig. 31: Relation between Excess Adiabatic Compressibility Vs Output Power for methanol mixed in toluene

Fig. 32: Relation between Excess Viscosity Vs Output Power for methanol mixed in toluene

Fig. 33: Relation between Excess Molar Refraction Vs Output Power for methanol mixed in toluene

Fig. 34: Relation between Excess Molar Volume Vs Output Power for methanol mixed in toluene

Fig. 35: Relation between Excess Intermolecular Free Length Vs Output Power for methanol mixed in toluene
The relationship between the excess parameters and the original parameters have been represented in graphs [fig.36-50]

**Fig. 36:** Relation between Adiabatic compressibility Vs Excess adiabatic compressibility for methanol mixed in toluene

**Fig. 37:** Relation between Free volume Vs Excess free volume for methanol mixed in toluene

**Fig. 38:** Relation between Acoustic impedance Vs Excess acoustic impedance for methanol mixed in toluene

**Fig. 39:** Relation between Dielectric constant Vs Excess dielectric constant for methanol mixed in toluene

**Fig. 40:** Relation between Viscous relaxation time Vs Excess viscous relaxation time for methanol mixed in toluene

**Fig. 41:** Relation between Absorption coefficient Vs Excess absorption coefficient for methanol mixed in toluene

**Fig. 42:** Relation between Gibb’s free energy Vs Excess Gibb’s free energy for methanol mixed in toluene

**Fig. 43:** Relation between Internal pressure Vs Excess internal pressure for methanol mixed in toluene
Future Applications: On the basis of output we can conclude that these sensors may have many applications after little advancement in sensing nodes of WSN, and IoT as indicated in [20, 21]

4. Conclusion
1. The experimental work has been carried out using a light source of operating wavelength of 660nm, two PCS fibers of 200/230μm diameter and 50cm in length each, a benchmark power meter, a uniformed U-shaped glass rod specific dimensions and toluene, methanol as chemical mixture at 303.15K temperature.

2. The refractive indices, densities, viscosity and ultrasonic velocity of all the mixtures have been determined using respective experimental instruments.

3. Using all the chemical liquid mixtures around U-shaped glass rod at the sensing zone the output powers are noted down at 303.15K temperature.

4. The variation of output powers due to the influence of parameters such as molar volume, molar refraction, dielectric constant, acoustic impedance, adiabatic compressibility, viscous relaxation time, intermolecular free length, Gibb’s free energy, free volume, internal pressure, effective mass, concentration and mole fraction have been measured and represented graphically.

5. The relationships between excess parameters on change in the output powers have been formed and shown them graphically.

6. The effects of excess parameters on the original physical quantities have been measured and the relationships are presented in graphs.

7. The present sensor enables to measure various unknown parameters such as density, viscosity, ultrasonic wave velocity, molar volume, molar refraction, dielectric constant, acoustic impedance, adiabatic compressibility, viscous relaxation time, intermolecular free length, Gibb’s free energy, free volume, internal pressure, effective mass, concentration and mole fraction at 303.15K temperature and at the wavelength of 660nm using toluene and methanol chemical mixture. The sensor also can be employed to determine the refractive index of any unknown liquids either dark or transparent in the dynamic range from 1.320 to 1.493 at 303.15K temperature.

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