FBG Refractometry and Electrical Impedance Analysis in Fuel Samples Characterization

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***Abstract*—This work reports the simultaneous use of electrical impedance spectroscopy and fiber Bragg grating (FBG) refractive index sensing in the estimation of the main components of specific fuel mixtures. Fuel samples containing gasoline, dehydrated ethanol, diesel, and kerosene were analyzed. Electrical impedance spectra and FBG sensor signals were registered for each mixture. Artificial Neural Networks (ANN) were used to estimate the ethanol concentration using the information from both sensors separately and to illustrate the methodology of fusing data from sensors that measure electrical permittivity at different frequency ranges, namely, an electrical impedance sensor and the etched FBG refractometric sensor. The behavior of the ANN to fuse data and the individual analysis of the sensor signals indicated that the joint use of the proposed techniques enhance the fuel estimation quality when compared to the usage of a singleton sensor.**

I. Introduction

The idea of using sensors, and specifically fiber optic sensors, to sense the distortions in the concentration of ethanol or adulterants in commercial fuels has been much discussed in the last decade as can be found in the literature [1], [2], [3]. In the case of long-period gratings, the sensor is naturally sensitive to the environment refractive index and in addition to that, the fuel has a refractive index that matches the sensors refractive index operation range [2]. The same occurs when using the FBG refractometric sensor [1]. However, only a refractive index sensor is not enough to determine with accuracy a fuel mixture with more than two substances, as illustrated by the case when ethanol is part of a solution of gasoline and an adulterant or even water [4]. If, for some reason, an adulterant is added to the commercial fuel sample, the refractive index may vary in the same proportion as when ethanol is added to the concentration of the fuel sample. This is an evident reason to choose an additional sensor to measure other varying parameters when the mixture is altered, as inferred by the methodology described in the literature, that measured density and the wavelength shift in the spectrum dip of a long period grating sensor [5]. Another sensor that has been proposed to measure the concentration of ethanol in gasoline can be used, and is based on a similar principle, namely, the measure of the electrical impedance of the sample at lower and radio frequency (RF) frequencies. Such a sensor requires simpler electronic circuits, but the obtained information is highly dependent on the temperature and is directly related to the electrical permittivity of the sample [6]. This additional sensor may reveal different properties of the sample in different frequency ranges other than the optical one by evaluating the electrical permittivity at extreme low frequencies up to radio frequencies (RF) in the tens of MHz range. Another similar measure in optical frequencies would be the refractive index variations of the fuel obtained with FBG sensors at the Bragg wavelength, which is a value usually in the infrared optical frequency range. The technique of extracting such new information from the electrical impedance of the sample, i.e. through the electrical permittivity, can in some cases help determinate the correct fuel concentration or adulterants in the sample. The resulting information can be computationally processed through the implementation of an artificial neural network (ANN) to fuse electrical permittivity information at low, RF and optical frequencies as the methodology presented in the following sections.

II. Methodology

A set of samples of gasoline, ethanol, diesel, and kerosene were prepared in order to determine the electrical properties of different fuel mixtures and their refractive index values.

The samples were analyzed using an electrical impedance analyzer to indirectly indicate the behavior of its electrical permittivity in different frequency ranges and a fiber Bragg grating etched sensor to indicate the refractive index changes in the fuel samples at the Bragg wavelength.

A. Analyzed Samples

Gasoline and ethanol fuel samples were bought from a local fuel distributor. The initial ethanol concentration in the gasoline was determined in the laboratory, and 17 other samples were prepared with gasoline and ethanol mixtures, with ethanol concentrations ranging from 26 % (the initial ethanol concentration in the gasoline) to 100 % (pure ethanol). These samples formed the data set *A*. A second data set (*B*) was formed using the gasoline (with 26 % ethanol), diesel and kerosene samples. This data set contained 3 gasoline and diesel mixtures with concentrations (percentage of gasoline and ethanol in diesel) of 80 %, 60 %, and 60 % respectively, and 3 gasoline (with ethanol) in kerosene mixtures with the

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