Heterogeneous measurement system based on optical fiber and ultrasonic sensors to determine ethanol concentration

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Abstract — **This work shows an heterogeneous measurement system to determine the ethanol concentration in ethanol-water blends. The system is composed by two sensors: an optical fiber refractometric sensor based on long-period grating and a sound velocity sensor based on a pair of ultrasonic transducers operating in transmission-reception mode. An artificial neural network was used to correlate the sensor responses and determine the ethanol concentration. The results demonstrate that the heterogeneous measurement system can predict, without ambiguity for a range between 0 and 100 % v/v, the ethanol concentration with maximum absolute error of 0.55 % v/v and 0.14 % v/v mean squared error, in validation step.**

Keywords - optical fiber sensor; sound velocity sensor; heterogeneous measurement system; ethanol-water blend.

I. INTRODUCTION

Ethanol is an alcoholic substance widely used by industrial sectors. It has been applied as a disinfectant in medicine and as solvent in pharmaceutical, chemical and food industry, especially in beverage products. Besides, the ethanol has becoming a popular biofuel and has been used as an eco–friendly alternative to fossil fuels [1]. Ethanol use reduces the emission of atmospheric pollutants, limits the shortage of fossil fuels and allows superior performance of internal combustion engines [1]. Furthermore, the ethanol comes from biomass sources of feedstock, such as sugar cane and corn, which are considered renewable resources [2,3]. Therefore, the ethanol use has been promoted worldwide, mainly to mitigate the greenhouse effect and to promote the sustainable development [1,4].

From a macroscopic point of view, ethanol and water are miscible and, generally, water is the major impurity in ethanol. The determination of ethanol purity degree is fundamental to define its cost and destination, so it is extremely important to develop sensors for evaluating ethanol-water blends. However, there are some issues about the measurement of ethanol concentration in ethanol-water blends because these constituents do not ideally mix on a molecular level, resulting in non-miscibility from a microscopic point of view [5,6]. Consequently, anomalous physicochemical properties are reported for ethanol-water blends which have been attributed to molecular segregation and cluster formation for both ethanol and water [7-9]. In a sense, the functional relation connecting parameters as refractive index or sound velocity and the ethanol concentration in ethanol-water blends is not a single–valued function within the overall range from 0 to 100 % v/v. For that, it is a challenge to develop ethanol measurement systems based on refractometric or ultrasonic principles.

Glass densimeter method [10] and Karl Fisher titration [11] can be used to determine the content of ethanol or water in the ethanol-water blend. Although widely used, these methods present high response time and low detection limit, as well as the need for a skilled operator to allow its correct implementation. Besides, they are not suitable for real-time monitoring, because they require sample extraction and post–treatment. Therefore, there is a great interest for developing alternative tools able to perform the ethanol-water blend analysis.

Optical fiber sensors, such as the long period gratings (LPG), when applied as refractive index transducers, show exclusive properties that allows its use as concentration sensor [12,13]. Among its features are the electromagnetic immunity, the electrical passivity, the non-chemical reactivity, the small physical size and the low response time. So, LPG refractometric sensors are ideal for real-time monitoring liquid mixtures [14]. Ultrasound transducers (UST) can also be used for such purposes [15,16]. UST allows simple and non–intrusive assessments as well as remote operations. In a combined configuration, LPG and UST sensors can constituted a powerful tool for evaluating liquid mixtures, especially ethanol-water blends although its anomalous properties. For that, it is necessary to merge the responses of both sensors in order to infer the ethanol concentration by means of mathematical models. Artificial neural networks (ANN) models are able to learn non-linear and complex behaviors as

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