

Hybrid optical fiber sensor and artificial neural networks system for bioethanol quality control and productivity enhancement

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ABSTRACT

Bioethanol is produced by bio-chemical process that converts sugar or biomass feedstock into ethanol. After bio-chemical process, the solution is distilled under controlled conditions of pressure and temperature, in order to obtain an ethanol-water solution. However, the ethanol concentration analysis is generally performed off-line and, sometimes, a re-distillation process becomes necessary. In this research, an optical apparatus based on Fresnel reflection has been used in combination with artificial neural networks for determination of bioethanol concentration in hydro-alcoholic solution at any temperature. The volumetric concentration and temperature effect was investigated. This intelligent system can effectively detect and update in real-time the correction of distillation parameters to reduce losses of bioethanol and also to improve the quality in a production plant.

Keywords: Intelligent optical fiber sensor, bioethanol productivity, quality control, neural networks.

1. INTRODUCTION

Nowadays, optical fiber sensors have been extensively used for *monitoring* key parameters, such as the cure of epoxy resins [1], temperature and strain [2], and refractive index [3]. Techniques using optical fiber sensors can be used to measure reduced sample volumes, with high sensitivity and employing equipments of small dimensions. The determination of solute concentration in liquids by optical techniques is mostly based on measuring its refractive index, with the advantage that it changes with the concentration of a solute in a solution with temperature and also with the light beam wavelength [4]. Optical techniques have been used to measure concentrations of liquid mixtures [3,4]. For example, it can be applied to determine bioethanol-water concentration [5,6], which is quite interesting since the precise measurement of bioethanol concentration is very important for industry and commerce. However, these techniques usually require expensive and sophisticated equipments, such as the measurement of: (i) wavelength shift in the FBG [6], or (ii) changes of intensity of absorption bands in the Raman spectroscopy [5] in the microstructured optical fiber. On the other hand, an optical reflectometer using the Fresnel reflection technique is not expensive, and it has the potential capability of on-line and remote sensing the concentrations of solutes.

Bioethanol is produced by sugar fermentation [7] or other biomass feedstock processes [8]. After the bio-chemical conversion process, the solution is distilled under controlled conditions of pressure and temperature in order to obtain a bioethanol-water solution. In Brazilian distilleries, the ethanol concentration analysis is generally performed off-line and, sometimes, a re-distillation process becomes necessary. Brazilian bioethanol fuel specification demands ethanol to be 92.6 to 93.8 % (m/m) hydrated ethyl alcohol fuel, or a minimum of 99.3 % (m/m) anhydrous ethyl alcohol fuel [9]. On-line bioethanol analysis can reduce time process (without re-distillation process), at the same time keeping quality control.

In the present research, we report a novel technique of artificial neural networks (ANNs) and optical fiber Fresnel reflectometer sensor for a real time determination of bioethanol concentration in bioethanol-water solution in an industrial processing plant.

2. MATERIALS AND METHODS

Nowadays, artificial neural networks (ANNs) have been applied to solve several problems in many areas [11-15], showing capability to obtain excellent results of mapping datasets $\{(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)\}$. Figure 1a shows the ANNs configuration where the Inputs x Outputs are linked by intelligent process. In a few words, ANNs consist on n inputs nodes, h hidden layer nodes, and m output nodes connected in a feed-forward fashion via multiplicative weights that can be arranged in a weight matrix W . The ANNs must be trained with historical data to find the appropriate values for the elements in matrix W , given the number of neurons in the hidden layer. In this paper, the learning algorithm employed is the well-known error back-propagation proposed by Rumelhart [16]. In this work, we used the multilayer perceptron ANNs to create the mapping to diagnose the concentration of the bioethanol-water solutions, through sign sent by the optical fiber sensor shown in Figure 1b, which represents a Fresnel reflectometer. In this apparatus, the laser generated optical signal (e.g., 10 mW, 1530 nm) is sent to an optical fiber sensor immersed in the solution (e.g., single-mode, 9/125, NA=0.2). Part of the light is reflected at the sensor-solution's interface and returns through the fiber into a detector. The light is converted to an electric signal [4,10], which is amplified and processed by a computer.

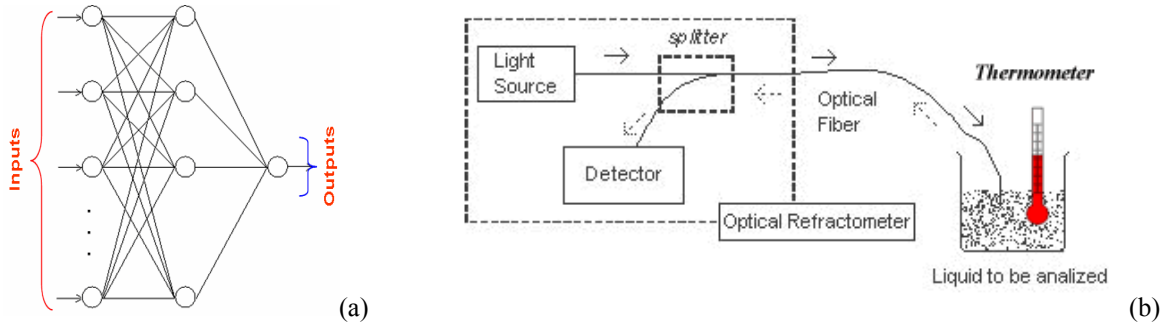


Figure 1. Schematic representation: (a) example of neural networks architecture; (b) optical fiber Fresnel reflectometer.

The intelligent system proposed in this paper uses the control capacity provided by ANNs together with the capacity of reading the optical fiber sensor, with the objective to analyze and to diagnose the physical meaning of the sign. The result of this analysis supplies relevant real time information to the operator to detect problems in several stages in the bioethanol processing plant.

3. RESULTS

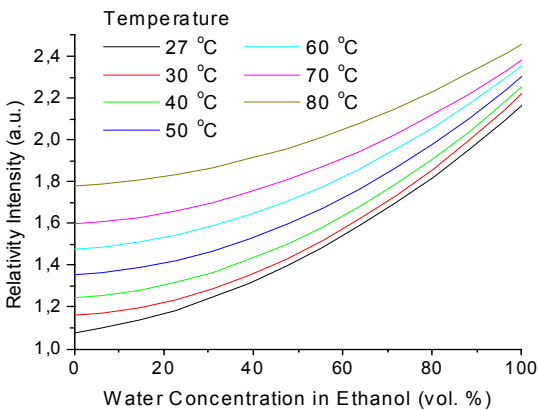


Figure 2. Relative Intensity versus Water concentration in Ethanol in different temperatures

the water content in the solution and with temperature (Figure 2).

When the difference between the refractive index of the solution and the refractive index of the optical fiber increases, the coefficient of reflection also increases (an increase in relative intensity) (Figure 2). This effect is described by Fresnel's equations, and the relative intensity increases with the increasing concentration of water in ethanol. It is observed that the relative intensity varies linearly with concentration, in the range 60 to 100 vol. % of water concentration in ethanol, indicating the linearity variation for refractive index with concentration, a similar result observed in literature [17]. However, our results indicate a non-linear refractive index variation (relative intensity) in the range 0 to 60 vol. % of water concentration in ethanol. The water-ethanol mixture has a volumetric and thermal complex properties [18,19], and we would expect the refractive index changes with the volumetric concentration variation, which follows the binary liquid compounds theory [20]. The relative intensity increases with the increasing temperature values, limited by the pure solution of ethanol and pure water. The relative intensity increases with

The proposed intelligent system works with the symbiosis of optical fiber sensor and neural model, monitored by a computer. For the system to be operational the neural model has to be adjusted to learn different behaviors of the bioethanol-water solutions. In the distillery industrial plant, the intelligent system is implemented after distillation system, and compromise the quality of ethanol production. As an example, a point to insert the sensor is shown in Fig. 3a. At the time the raw material characteristic changes, it can introduce bioethanol loss/gain in the residue (discarded solution) that can effectively be detected in real time.

The neural model was adjusted to capture the information of the temperature and of the sign read by the optical sensor (volts), to supply detailed information about the concentration of the bioethanol-water solution. The architecture of the neural model used presents 2 neurons in the input layer and 1 neuron in the output layer. Physically, the chosen architecture for the neural model maps this pattern (Figure 3b). After the training step, the intelligent system was submitted to several real situations (temperature x voltage) to evaluate its performance in the various situations existent in the bioethanol production plant. In a general way, it can be concluded that the ANNs is effective to provide excellent results identifying the concentration ratio of the bioethanol-water solutions correctly in real time. The proposed intelligent hybrid optical fiber sensor system presented errors of the order of 2%, and usually fails in the control process associated at the noise level present in the measured data. The present technique of *optical fiber sensor system* can be optimized by the manufacture of a special optical fiber of much higher index of refraction [21].

The intelligent system identifies the bioethanol concentration and can control the distillation process parameters, for example, when temperature increases, non-distilled ethanol in the residues decreases, but when the flow of fermented solution is higher, the ethanol concentration in the distilled solution increases, but also, the ethanol loss increases in the residue. The distillation process parameters should be up-to-dated on-line with ethanol concentration analysis, shown in figure 3a.

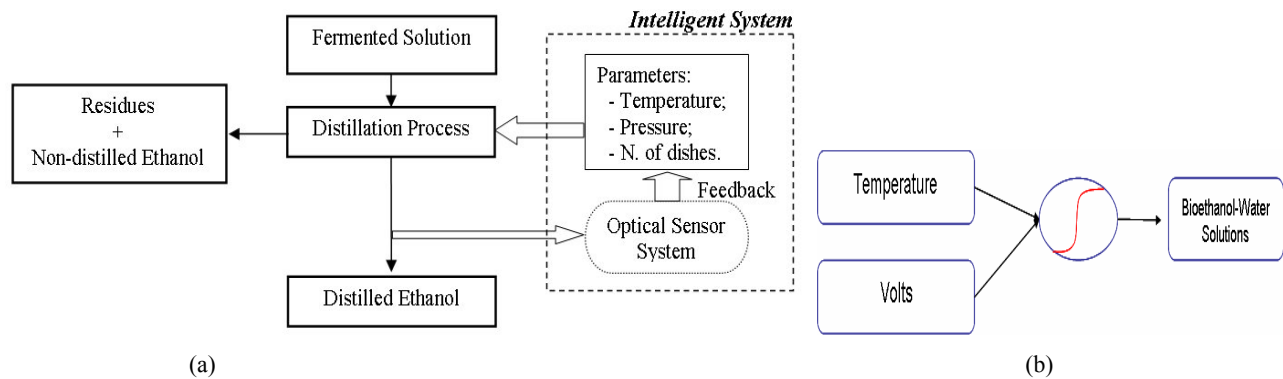


Figure 3. (a) The monitoring point of optical fiber sensor and feedback in a simplified schematic diagram of the distillery., (b) Proposed model of input versus output informations..

4. CONCLUSIONS

The intelligent hybrid optical fiber sensor system is very effective for real time determination of bioethanol concentration with temperature effect correction in an industrial process. It can improve the quality control and reduce the non-distilled ethanol which usually are lost. For large scale industrial production, such as the case of a plant of 2 million liters bioethanol per day, the present technology can represent an important breakthrough to improve quality and productivity.

5. ACKNOWLEDGMENTS

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