Enhancing Productivity of Bioethanol Processing by Optical Fiber Sensor System

Carlos K. Suzuki[1], Eric Fujiwara[1], Eduardo Ono[1], Carlos E. V. Rossell[2]

[1]UNICAMP – The State University of Campinas, Faculty of Mechanical Engineering, Laboratory of Photonic Materials and Devices (LIQC), 13083-970 Campinas, Sao Paulo, Brazil

[2]CTBE – Brazilian Bioethanol Science and Technology Laboratory, Campinas, Sao Paulo, Brazil

Presently, more than fifty percent of the Brazilian gasoline demand has been substituted by sugarcane based ethanol. Its cost is highly competitive, even though without subsidies. Such a use of sugarcane ethanol is being adopted by other almost one hundred countries around the world due to its advantage in terms of social and environmental sustainability. Recent studies conducted by Brazilian Bioethanol Science and Technology Laboratory (CTBE) indicate that the use of 7% of the total area currently used for agriculture in Brazil, if dedicated to cultivate sugarcane, it becomes possible to produce enough amount of bioethanol (1st generation processing) to displace almost 10% of worldwide gasoline use in 2025. On the other hand, analysis of the current production process has shown several flaws identified in 15 sub-processes stages, such as sugarcane washing, milling, evaporation, fermentation, distillation, rectification, etc, involving considerable losses to attain more than 10% of total production, which represent economical loss of billions of dollars. Notably, part of these losses can be attributed to the lack of control of the ethanol concentration during the various processing stages. Currently, almost all sugarcane-based ethanol industries use laboratorial techniques to supervise the alcoholic content, such as infrared spectroscopy or chromatography methods.

Regarding these problems, the development and application of new technologies to minimize these losses is of fundamental interest, both on the economical and sustainable points of view. In this context, optical fiber sensors can be considered as one of the most promising technologies, providing the real time and high-sensitive measurement of the alcoholic content. In addition, fiber sensors can offer a sort of advantages in contrast to other methods, such as low disturbance to the plant processing, resistance against harmful environments, remote sensing and no explosion risks. Nowadays, a large variety of fiber sensor systems has been developed, based on fiber gratings, near-infrared spectroscopy and evanescent wave detection, for example.

In present research, the implementation of an optical fiber reflectometer for the determination of the ethanol concentration in process streams of the bioethanol plant is demonstrated. The end face of a single-mode fiber is immersed on the liquid sample and actuates as the sensor probe. According to the Fresnel principle, the light reflectance in the fiber-liquid interface is a function of the fiber core and sample refractive indexes. Moreover, the refractive index of an ethanol-water mixture can be correlated to the sample concentration and temperature, and the light wavelength.

The sensor calibration was performed by the measurement of binary hydro-alcoholic mixtures prepared by mixing anhydrous ethanol and distillated water. The variation of the reflected light intensity as a function of the samples concentrations was adjusted by a 5^{th} order polynomial fitting. Subsequently, the process streams were analyzed for the prediction of the alcoholic content. In this research, the tested samples were the fermentation vat content, CO_2 wash water from the scrubber, the clarified wine, vinasse, flegmass and the hydrous ethanol. All experiments were conducted at room temperature, for the laser source wavelengths of 1310 and 1550 nm. The data acquisition module sampling time was adjusted to 1 kH.

The measurement of pure ethanol-water mixtures indicated an average error of less than 1.5 vol% on the calculation of the alcohol content. Regarding the analysis of the process streams, the fiber sensor provided the correct identification of the ethanol concentration, with measurement errors of less than 3 vol% for the CO_2 wash water, clarified wine and hydrous ethanol samples. In case of the fermentation vat content, an error of ~4 vol% was obtained. The increase on the measurement error can be attributed to the presence of other substances on the sample composition than water and ethanol, such as sugars, minerals and impurities, which causes variations on the refractive index of the liquid sample.

On the other hand, the measurement of the ethanol content on the vinasse and flegmass was not possible with the current sensor configuration, since the concentration of these samples (<1 vol%) is not detectable. In this sense, the research group is currently developing specialty optical fibers for high-sensitive sensor probes, in cooperation with institutions in Japan and Sweden.

The results show the capabilities of presented technology on fulfilling the needs of bioethanol and sugar production units, especially the medium and large scale plants, whose implementation can generate a great impact in the productivity with a considerable financial gain.

Keywords: Economic impacts, Optical fiber sensor, Process monitoring, Sugarcane bioethanol.

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