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DEVELOPMENT OF A SALINITY SENSOR USING ETCHED FIBER BRAGG GRATINGS[1]

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ABSTRACT

This article presents an approach to the application of a salinity sensor based on etched fiber Bragg grating inscribed in single mode fiber. A potential application for this sensor is the salinity monitoring in brine tanks in dairy where this physicochemical parameter is one of the most relevant in quality control in cheese production. Two EFBGs with the same characteristics were used, both sensitive to the variation of the refractive index for the different levels of salinity concentration and temperature measured. Tests were carried out with typical temperatures and concentrations found in brine tanks. A linear regression was used to evaluate the relationship between Baumé degrees and salt concentration, and between the Bragg wavelenght shift and salt concentration, with a non-linear relationship between the parameters being observed.

Palavras-chave: Etched Fiber Bragg Grating, refractive index, brine, salinity, salt concentration, temperature, cheese.

I. INTRODUCTION

In Brazil there are several types of cheese being produced and consumption increases every year. Cheese is a dairy product obtained by separating the whey after the milk has coagulated. After removing the whey, in most cheeses, the mass goes through stages of pre-pressing, shaping, pressing, salting and maturation [1]. The brine salting method is used in most cheeses, making it the most used process in Brazil. [2]. The brine is basically composed of a solution of water and salt. The average concentration of salt in the brine tank is between 20% to 24%, the solution is in stainless steel tanks with controlled temperature. One of the main functions of brine is to control the growth of microbial activity, regulation of enzymatic and physicochemical processes, durability and other characteristics of the cheese [3]. For the quality control of the brine, the physical-chemical parameters such as temperature, pH, acidity and salt concentration are checked. In measuring the salt concentration, the Baumé areometer, also known as a hydrometer, can be used, another

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system that can be used is the refractometer, but both methods require taking a sample from the solution, so the measurement is manual and accuracy around 1%. An alternative solution to these disadvantages would be the use of optical sensors, which can be an option for greater accuracy and real-time monitoring.

Among optical sensors, Fiber Bragg Grating (FBG) are very versatile sensors, with an intrinsic ability to measure a range of parameters such as strain, temperature, pressure, chemical and biological agents, among others. In addition, they have a good flexibility due to their small size, low losses, electromagnetic immunity, reduced weight and costs, because of these numerous advantages, FBGs are the object of several studies. For measurement of salinity concentration there are some applications that have already been studied, such as the use of FBGs using hydrogels [4], FBGs with polyimide coatings [5], and the use of EFBGs [6], among others. In one of the studies, the wet corrosion technique was used to increase the sensitivity of the optical fiber for measuring salinity. This technique has already been tested in the measurement of salinity and temperature using a fiber optic Bragg grating [6] and in multimode fiber Bragg gratings [7] measuring glycerin concentrations in water and biodiesel.

This work consists of measuring salinity using a single mode Etched Fiber Bragg Grating (EFBG) to measure the concentration of sodium chloride (NaCl) dissolved in water. In a first stage, this research was carried out in laboratory tests and later it will be held in the field, with the objective of measuring the average concentration of salt in brine tanks used in cheese production in dairy products.

II. MATERIALS AND METHODS

A. Description

For the measurement of salinity, EFBGs inscribed in single-mode fibers were used, whose sensitivity to the external medium is based on the interaction of the evanescent field with the external refractive index obtained due to its reduction of the fiber cladding [8].The technique used was wet corrosion, in which the reduction of the fiber cladding to the core region is obtained by means of hydrofluoric acid (HF).

B. Essays

To measure the brine salt concentration, a digital scale was used to weigh the mass of sodium chloride (NaCl) to be dissolved in water. The solution (H2O + NaCl) was obtained by stirring it inside a glass beaker until homogeneous, the degrees Baumé (°Be) were measured with the aid of a graduated cylinder using a sample of the solution already homogenized and and using a Baumé areometer, also known as a hydrometer, the reading was taken with the aid of its scale was taken and the process repeated at each new concentration.

The sensor was immersed inside the glass beaker with the already homogenized solution that was partially immersed inside the PolyScience 9002B thermal circulator, this equipment has a reservoir with a quantity of distilled water and with the aid of a lid it provided an approximately adiabatic environment, ensuring constant temperature and with good accuracy. This equipment was used to maintain the temperature of the fixed solution, while the tests were performed with different concentrations of salt, the collected data were obtained in the SI101 optical interrogator with a sampling frequency of 1 Hz, via the Catman Easy software, the data collected the data were used to analyze the EFBG spectrum with the aid of Matlab software.

The temperatures tested were 10 °C and 20 °C, based on the controlled temperature range that is used in brine tanks in dairy products in cheese production, which is usually in the range of 10 °C and 15 °C needed for to prevent the growth of microorganisms undesirable [2]. The concentrations of salt (sodium chloride) were in the range of 0% to 24%, which is adopted in the production of cheeses that use the process of salting in brine [9].

Two tests were carried out, the first at a temperature of 10 °C and the second at 20 °C, where were 300 ml of water was added in a glass beaker with different concentrations of salt dissolved. For calculation purposes, the density of water was considered to be approximately 1 g / cm³, so we have then that 1 ml is approximately 1 g, to facilitate the test, the common percentage concentration was calculated as the ratio between the mass of the solute, which is the salt by the sum of the masses of the solute and the solvent, which is the water for this solution, defined by:

$$C\,(\%) = 100\,(\text{Mass of solute}) \,/ (\text{Mass of solute} + \text{Mass of solvent}). \quad (1)$$

The theoretical linearized percentage concentration was obtained through a linear regression of the values found in Table I [10], which relates the degrees Baumé with the concentration of salt used in brine in cheese production. Keeping the volume of water constant, it is adding different amounts of salt generating new concentrations in the same solution, similar to the salt corrections carried out in brine tanks in dairy products. The data from the calculated concentrations used in the assays together with the linearized concentrations are shown in Table II and Table III.

Table I | Data Related To Brine

Density	Degrees Baumé (°Be)	Salt concentration (%)
1	0	0
1.012	1.8	1.792
1.026	3.8	3.695
1.058	7.9	7.919
1.078	10.5	10.558
1.102	13.3	13.725
1.118	15.3	15.837
1.147	18.6	19.532
1.164	20.4	21.644
1.186	22.2	23.775
1.204	24.6	26.395

Table II | Essay Data With 20°C

Total mass of NaCl (g)*	Degrees Baumé (°Be)	Calculated salt concentration (%)	Linearized salt concentration (%)
0	0	0	0
15	5	5	5
30	8	9	8
45	12	13	13
60	16	17	17
75	19	20	20

* Grams of salt for a fixed volume of 300 ml of water.

Table III | Essay Data With 10°C

Total mass of NaCl (g)*	Degrees Baumé (°Be)	Calculated salt concentration (%)	Linearized salt concentration (%)
0	0	0	0
45	13	13	14
75	19	20	20
90	22	23	23

* Grams of salt for a fixed volume of 300 ml of water.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The data represented in Table I are used as a reference for the correction of brine solutions, in practice the frequency of changing the solution for a new one is small, it takes months, being at the discretion of each dairy, so it is common to correct it after manufacturing of batches of cheeses that use this salting process. Through a linear regression of the values of degrees Baumé and salt concentration, it is possible to compare the calculated concentration with the linearized one, it is observed that the values were very close, however, the measurement uncertainty must be taken into, because it is obtained by reading the meniscus resulting from the immersion of the hydrometer in the graduated cylinder, resulting in an approximate error of 1 ºBe.

The treatment of the data obtained in the tests was carried out with the aid of the Matlab software, it was observed that, in the test at 10 ºC, the signal reflection peak had an attenuation in the region between -30 dB to -34 dB and in the test at 20 ºC was between -27 and -30 dB. Both were tested with two different EFBGs, even inscribed with the same characteristics and tested in the same way, the quality of the sensor splice with a single-mode pigtail ends up influencing the attenuation of the generated signals. The increase in the dissolved salt concentration in the solution resulted in a gradual shift to the right of the Bragg wavelength, this behavior is generated by the increase in the external refractive index, which results in a longer wavelength. The respective optical spectra are shown in Fig. 1 and Fig. 2.

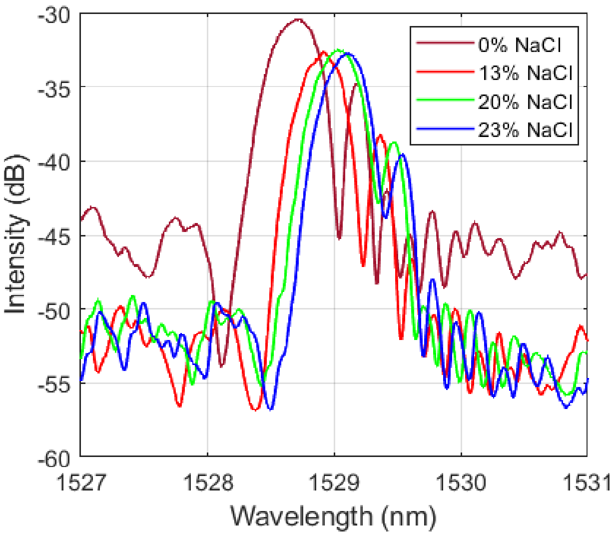

Fig. 1. EFBG spectrum for different salinity concentrations at a temperature of 10 ºC.

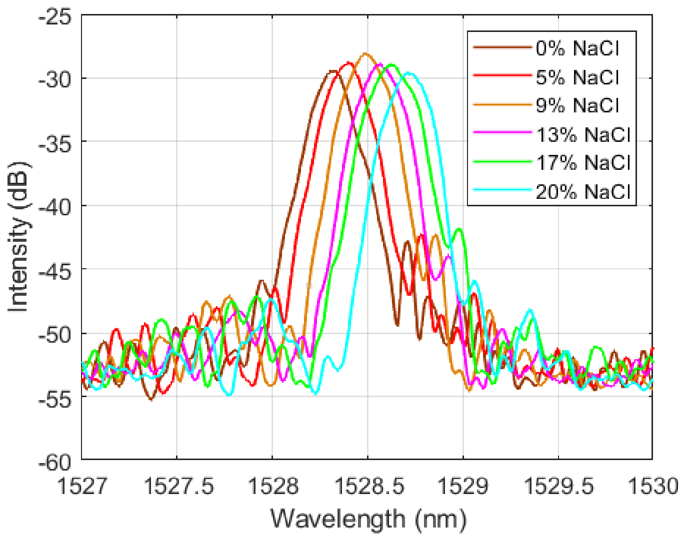

Fig. 2. EFBG spectrum for different salinity concentrations at a temperature of 20 ºC.

Other possible reasons for the signal pattern to differ between tests is the bending effect suffered by the optical fiber. During the tests, the sensor was fixed on a small acrylic plate for mechanical protection, and this must be in a vertical position inside the thermal bath. This leads to small bends in the optical fiber, generating some divergences in the intensity of the signals measured by FBG sensors. Another factor that directly influences is temperature, as it is related to the solubility of the solute (NaCl) with the solvent (H2O), therefore, the higher the temperature of the solution, the easier the solubility and the lower the probability of a measurement error occurring, as there will not be as much salt deposited at the bottom of the solution when the concentration is close to saturation. For the comparison between the tests, the pattern of displacement of the Bragg wave was analyzed with a linear adjustment due the similarity with the concentrations used in practice (Table I). In Fig. 3, it is possible to verify that the R^2 factor was reduced for the analyzed data, presenting a little linear relationship. Increasing the temperature from 10 ºC to 20 ºC the sensitivity was from 0.0169 nm /% to 0.0207 nm /% showing a greater sensitivity with increasing temperature due the slope of the straight line is proportional to the sensitivity. A larger number of points is necessary to verify which adjustment will be better in the relationship between wave displacement and salt concentration.

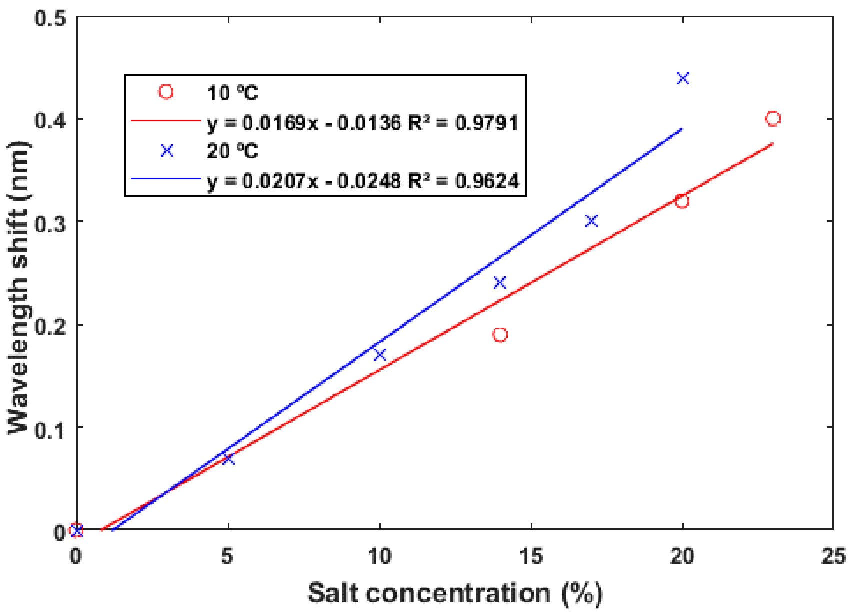

Fig. 3. Salt concentration as a function of wavelength displacement for the tests at 10 ºC and 20 ºC.

For an effective interpretation of the tested data and for practical application, one possibility is the use of algorithms to identify patterns in the response signals to variations in salt concentration, in order to have a direct reading of the parameter of interest. However, it is necessary to improve the experimental arrangement for future work to avoid bending the optical fiber.

IV. CONCLUSION

From the tests performed with single-mode EFBG, it was possible to observe that the displacement of the Bragg wave occurred gradually and proportionally to the increase in the concentration of dissolved salt in a homogeneous brine solution. With exposure to temperatures of 10 °C and 20 °C, it was observed that the displacement was within the expected range and the relationship with the salt concentration did not occur linearly, as shown in Fig. 3. It is also possible to notice that with increasing temperature the sensitivity to variation in salt concentration increased. Following this work, a way to increase the robustness of the sensor will be investigated, which will be used in the field to measure physicochemical parameters of salt concentration in brine tanks in cheese production.

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