Sodium Chloride Concentration Measurement via Optical Fiber Tip Sensor

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Abstract. Sodium chloride (NaCl) is an essential compound that human needs mainly to regulate the amount of water in body. However, the level intake of NaCl daily consumption should wisely be regulated. Previously, various techniques have been employed to measure NaCl concentrations but high cost and complex fabrication become one of the limitations that need to be overcome. Thus, this paper demonstrates a sodium chloride (NaCl) concentration measurement using an optical fiber tip sensor. The flat end facet of single – mode fiber was used to emit the broadband light at near infrared wavelength region to detect NaCl at different concentration ranging from 0% – 4%. The optical power reading was recorded at every increment of 0.5% of NaCl concentration. When the aqueous NaCl was dropped onto the sensing region, the optical power decreases as the NaCl concentration increases. This experiment has shown that the sensitivity achieved by this sensor was 0.1239 dBm/% with regression value up to 0.999.

1. Introduction
Sodium Chloride (NaCl) is also known as salt in chemical term, is made up of sodium (Na+) and chloride (Cl-) ions [1]. It appears as crystalline cubes, soluble in water and give a salty taste. Salt most commonly used in food industry for food seasoning or natural preservative [2]. While in medical industry, NaCl is used as for fluid loss treatment and NaCl balance, helping the patients that are incapable to take nutrients and fluids by mouth [3]. Nutritionally, NaCl are essential to regulate the amount of water in human body [4] and maintain the condition of blood pressure especially to individual who are in their middle-aged to elderly with a family history of hypertension [5].

Even though the intake of NaCl is important, its level in the body should wisely be regulated. It is advised to aware with average daily consumption which not too little or too much because it can be harmful to human health. The World Health Organization (WHO) had standardize the recommendation dietary salt intake is around 5g per day [6] and those have risk of heart disease are better to consume less than 2 grams of sodium per day [7]. Excessive level can cause hypernatremia, but lack of NaCl can cause hyponatremia [8, 9]. Extremes hyponatremia can lead to muscle twitches and seizures. While hypernatremia involves in dehydration due to not drinking enough fluids, diarrhea, diuretics and kidney dysfunction [10].

Based on previous studies, various techniques have been employed to measure the concentration of NaCl via optical fiber sensors such as long period fiber gratings (LPFGs) [11], surface plasmon
resonance (SPR) [12], and tapered plastic multimode (PMM) [13]. However, there are some limitations need to be considered including complex sensor fabrication and high cost.

Thus, this paper proposed an optical fiber tip sensor to monitor the NaCl concentration. The main advantage of this sensor is on the fabrication process. Due to simple step of fabrication process, an optical fiber tip sensor has attracted attention in sensing field with the fabrication of flat end-facet sensing surface by only cleaving the tip of the optical fiber [14]. Previously, optical fiber tip sensor has been utilized for measuring acetone, methanol, benzene concentration [15], ethanol and sucrose level [16].

Based on these references, it is proven that optical fiber tip sensor can be utilized for monitoring NaCl concentration. Therefore, an optical fiber tip sensor for NaCl concentration measurement is proposed and demonstrates. The proposed sensor measures the output reading and monitor the changes of optical power at different concentrations influenced by the interaction of Fresnel’s reflection produced at the boundary between the fiber tip and the analyte solutions. This work offers simplicity, reliability, and continuous capability of measurement.

2. Research Methodology

A single-mode fiber (Corning SMF-28e) with the core and cladding diameters of 9 μm and 125 μm respectively was used. This experiment used SMF as the sensor because it produces low light loss [17] and has better performance in measuring small phase changes in light transmitted through the sensing region [18]. Next, the tip was cleaved by using a high precision cleaver to produce a flat end surface. The sensor characterization for NaCl concentration measurement was carried out by the experimental setup shown in Figure 1.

![Figure 1](image_url)

**Figure 1.** Experimental setup for the purposed NaCl concentration detection using a single-mode optical fiber tip sensor

The experimental setup consists of broadband light source (Fiberlabs – ASE FL7004), optical circulator (Thorlabs – 6015-3-FC) and optical spectrum analyzer (Thorlabs – OSA205C). OSA is used to monitor and record the sensing spectrum at ideal wavelength, 1550 nm. This is because 1550 nm has low loss absorption of the glass material used in optical fiber is minimum, 0.2 dB/km. The broadband spectrum is required to trace both optical power and wavelength changes. The optical circulator is used to allow the transduced light (Fresnel light) travel in only one direction from the sensing region directly to the OSA for monitoring sensing response. To reduce any physical disturbance, the sensor was fixed inside the beaker and allowing the immersion of tip onto the mixture.

Figure 2 shows the process of NaCl samples preparation. For continuous monitoring purposes, the analyte was prepared by adding 0.5g of NaCl powder (R&M Chemicals) to increase the concentration. To begin with, a 100mL of deionized (DI) water is poured into a beaker and placed on the hot plate. Whilst stirring in a moderate speed, the first concentrated sample is made by adding 0.5g of NaCl powder into the beaker and continue stirring the mixture for 6 minutes to ensure homogeneity. The
following sample was continued by adding another 0.5g of NaCl powder into the same beaker to get a various NaCl concentration ranging from 0 - 4 %.

**Figure 2.** Concentrated NaCl sample preparation for continuous measurement

Due to limited instrument to measure the analyte refractive index at near infrared wavelength, the refractive indices of all samples were determined by using a digital refractometer (Atago – PALRI 3850) operating at UV wavelength. DI water is used to calibrate the refractometer before measurements to ensure the neutralization of the device. The experiment was repeated for three cycles and conducted in a constant room temperature (23°C). To determine the NaCl concentration, the concentration can be calculated by using Equation (1).

$$\text{Concentration (wt\%) = } \frac{\text{mass of NaCl powder (g)}}{\text{mass of solution (g)}} \times 100\% \tag{1}$$

2.1. Sensing Mechanism

As illustrates in Figure 3, the sensing principle is mainly based on Fresnel reflection, that occurs at the coupling interfaces between the tip of optical fiber and the analyte that have different refractive indices. Theoretically, some of the light will be transmitted and some of the light will be reflected once the light propagates through a boundary that have different refractive index. The intensity of reflection can be determined as in Equation (2).

$$R = \left( \frac{n_c - n_a}{n_c + n_a} \right)^2 \tag{2}$$

where $n_c$ is the refractive index of the core optical fiber and $n_a$ is the refractive index of the analyte contacted at the core. The working principle of the proposed sensor used in this work is illustrated as in Figure 3. Fresnel reflection occurred at the sensing region will arising when the different composition of $n_a$ changes.
3. Result and Discussion

As depicted in Figure 4, the refractive index of the NaCl concentration samples was recorded and analyzed for reference purposes. As the NaCl concentration increases from 0% – 4%, its refractive index also increases from 1.3358 to 1.3421 with total changes of 0.0063. Based on the plotted graph, it is worth to mention that the changes in chemical composition will affect the refractive index of the analyte.

Figure 4. Refractive indices of NaCl concentration samples at 0% – 4%

Figure 5 shows the sensing spectra of the first cycle of experiment when measuring the NaCl concentrations. The full optical sensing spectrum images throughout all measurements are plotted as in Figure 5(a). From the inset image in Figure 5(b), there is no significant spectral changes shown by the proposed sensor towards the NaCl concentration changes. Initially, at 0% of NaCl concentration, the light propagates at -42.243 dBm, but slowly decreases to -42.699 dBm when the NaCl concentration increased up to 4%.
Figure 5. The sensing spectrum (a) full spectra (b) inset image of peak spectra

Figure 6 shows the analysis of the optical power and wavelength changes from the sensing spectrum. As can be seen from Figure 6(a), the peak wavelength at 1559 nm are constant for each NaCl concentration. Hence, the sensor performance was evaluated based on the optical power changes. Figure 6(b) shows the optical power changes towards the NaCl concentration. The optical power decreases as the NaCl concentration increases. The total power loss for the experiment is 0.4746 dBm with initial reflected light of -41.4323 dBm is then reduced to -41.9067. It shows that the optical power linearly decreases as the concentration of NaCl increases. The sensor sensitivity can be determined from the slope of the graph. The sensitivity achieved by this sensor is 0.1239 dBm/% with a linear regression value up to 0.9.

Figure 6. Analysis of the sensing spectrum based on (a) optical power (b) wavelength changes

Table 1 summarizes the sensor performance of the experiment for three repeated cycles and give the average sensitivity of 0.1150 dBm/% and the linearity of 98.10%. The sensitivity of the sensor is recorded from three repeated cycles and evaluated based on their standard deviation. The evaluation is needed to monitor the changes in the results. The sensor sensitivity has a standard deviation of 0.0126 which shows low variation in sensitivity between three repeated experiments. All three sensors sensitivity is close to the average value, hence define the sensor has high possibility to produce a constant sensitivity for any repeated experiment.
Table 1. Optical fiber tip sensor performance towards NaCl concentration at three repeated experiment

| No. of Cycles | 1     | 2     | 3     |
|---------------|-------|-------|-------|
| Sensor Sensitivity (dBm/%) | 0.1239 | 0.1006 | 0.1206 |
| Regression Coefficient, R²   | 0.999  | 0.9655 | 0.9785 |
| Average Sensitivity (dBm/%)  | 0.1150 |       |       |
| Linearity (%)                | 98.10  |       |       |
| Standard Deviation of the Sensitivity for three repeated experiment | 0.0126 |       |       |

4. Conclusion
In summary, the application of optical fiber tip sensor for NaCl concentration measurement from 0% – 4% of concentration has been successfully demonstrated. The proposed sensor provides a good performance at average sensitivity of 0.1150 dBm/%, average linearity of 98.10% and standard deviations of 0.0126. The optical fiber tip sensor is easily and inexpensively fabricated. As the sensor is sensitive towards the NaCl concentrations ranging 0 – 4%, which encompass the WHO recommendation daily NaCl consumption intake of 5g, making this an important early stage towards development of simple, sensitive and low-cost sensor to monitor the NaCl concentration in any foods. This direct detection of NaCl concentration is a considerable interest in this work.

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