SELF-POWERED SWEAT ION SENSOR WITH LONG DURATION ELECTROCHEMICAL POTENTIAL

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ABSTRACT

The focus of this work lies in the construction of a long-lasting self-powered sweat ion sensor in a galvanic cell configuration of notation Mg(s)|NaCl(aq)|Cu(s), preliminary analysis on expected output of the sensor was obtained using the Nernst equation, then several controlled tests were carried out in the laboratory using different molar concentrations of NaCl in aqueous solution to later carry out tests with human sweat. The results showed that the ion sensor allows the monitoring of electrolyte levels in sweat in the 0.01-0.2 molar range, with a useful life of the electrodes greater than 10 days; the sensor output potential is greater than 1.53 volts when the sensor is in contact with the NaCl electrolyte and greater than 1.46 volts when the electrolyte is human sweat.

KEYWORDS

Electrochemical sensor, ions sweat, electrolyte, self-powered.

INTRODUCTION

The monitoring of ions in sweat is essential to detect imbalances in the human body, such as hypohydration and hyperhydration, due to the variation of sodium and chloride present in sweat. It is also possible to carry out an early screening for cystic fibrosis (CF), which is a genetic condition that affects the cells that produce the mucosa, sweat and gastric juices, when concentrations exceed a value of 0.06 M of chlorine in sweat [1].

The chemical components mostly present in human sweat are sodium and chlorine with molar concentrations of ~10-100 mM/L and ~10-78 mM/L respectively [2]. The main characteristic of sodium and chlorine is that they are charged ions electrically with positive charge and negative charge respectively, and due to this quality it is possible to detect them in aqueous solutions through electrochemical methods, among them, the simplest method is the potentiometric measurement, which requires the use of two metallic electrodes, one of them is the electrode of work and other is the reference electrode, and between them the electrolyte of interest in aqueous solution, its output is an electrical potential called E and measured in volts. The electrochemical potential obtained from the sensor is described through the Nernst equation (equation 1), which relates the process of a chemical oxidation-reduction reaction within an electrochemical cell, using for this, E0 values called standard potential, as well as, the constants of the ideal and Faraday gas and the molar concentrations of the elements that participate in the oxidation and reduction processes in that reaction [3].

$$E = E^0 + (RT/F * \ln [Ox]/[Red]) \quad (1)$$

The electrolytes monitoring of in sweat through the potentiometric method still presents several areas of opportunity aimed at improving: the operating range, the duration of the sensor electrodes, and increasing the output potential. In 2019, a measurement of chlorine in sweat was reported [4], this was carried out through a disposable self-powered patch with a limited output potential of 1.3 V and operation of only a few seconds to detect cystic fibrosis, resulting in only one result positive or negative [4]. On the other hand a sensor for the detection of sodium and potassium in human sweat during exercise was reported in 2020 [5], it was built to deliver a small output potential of 280 mV, making it dependent of external batteries, and their carbon electrodes require a complex chemical manufacturing process. In addition, it is worth mentioning that the works cited above and those currently reported do not exceed electrolyte concentration measurement values above 100 mM/L. This work focuses mainly on solving the problems associated with: increasing the measurement range of molar electrolyte concentrations greater than 100 mM/L, increasing the output electrochemical potential E above 1.3 volts, and improving the sensor timelife, so that it can be part of a continuous sweat electrolyte monitoring system.

MATERIALS AND METHODS

Cell construction

The self-powered sweat ion sensor is built on a Medimart brand flexible absorbent adhesive patch, high purity (99.95%) magnesium tape for the ion sensing electrode, and 24 gauge copper foil (0,022 in) for the reference electrode (purchased from Fisher's Labs) in a galvanic cell configuration as shown in Fig. 1 b, both electrodes have dimensions of 0.15 x 0.31 inches and the separation between them is 0.11 inches. For the laboratory testing stage with NaCl solutions, a cell was built with the mentioned electrodes inside a transparent microcentrifuge tube (Fig. 1 a). For the testing stage with human sweat, the electrodes were attached to the flexible patch using Steren brand double-sided tape parallel to each other so that there were no problems related to the small amounts of sweat secreted by the skin. The electrodes were soldered with strands of 28 AWG gauge flat copper wire to be connected to the instrumentation. It should be noted that two pairs of electrodes were connected in series in order to obtain voltages greater than 3 volts and power supply the instrumentation.

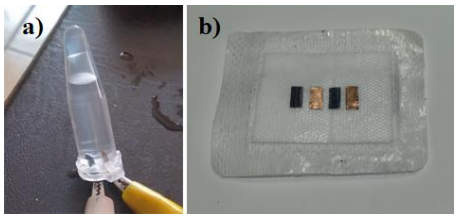

Figure 1: a) Cell for laboratory tests and b) sweat ion sensor in the form of a patch.

Instrumentation and communication

Potential measurements in the laboratory with aqueous NACl solutions were carried out using a Fluke brand digital multimeter, model F15B+ with auto range, measuring only readings related to voltage in volts.

For the measurements in tests with human sweat, a simple instrumentation was carried out on the patch to collect the data from the sensor, it consisted of using the Atmel brand ATtiny85 microcontroller that is capable of operating with a voltage of 1.8 volts, its analog-digital converter to digitize the signal and be able to manipulate it through code with the Arduino IDE application. A Bluetooth BLE module based on the Texas Instruments CC2541 chip was connected to the microcontroller in order to wireless

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signal transmission (Fig. 2 b), which can operate with a minimum supply voltage of 1.8 volts. The send data can be viewed in an own mobile application designed for android operating system Fig. 2 c.

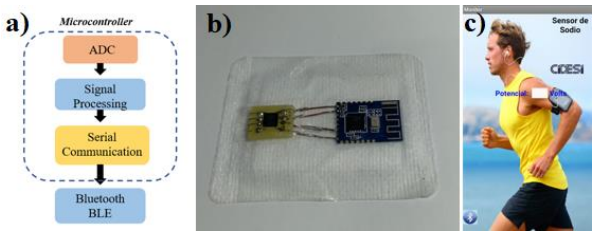

Figure 2: a) Block diagram of the instrumentation, b) microcontroller connected to Bluetooth BLE and c) mobile app.

RESULTS AND DISCUSSION

Initially, mathematical calculations were made with the Nernst equation that showed a range of potentials from 2.78 to 2.84 volts for a molar concentration range of 20 mM/L-160 mM/L Table 1, because these calculations are made taking into account conditions ideal and standard. Subsequently, two stages of tests were carried out with the ion sensor, the results are shown in the following subsections in the form of graphs.

Laboratory tests

Using the cell built especially for these measurements, the results in the Fig. 3 were obtained, which show a cell output potential of 1.53 to 1.6 volts for a molar concentration range of 20 mM/L-160 mM/L. The difference with the results of the mathematical analysis is up to 1.19 volts because the mathematical calculations using the Nernst equation consider standard values obtained with electrodes with large electrode dimensions and standard concentration, pressure and temperature conditions. Regarding the duration of the sensor, measurements were made in the laboratory after 3 weeks after the first tests, which only showed a decrease in potential of 8%.

Table 1: Calculations and measurements of potential with cell: Mg|NaCl|Cu.

[M]	Nernst Equation (V)	Experimental (NaCl) (V)
0.02	2.7794	1.534
0.04	2.7972	1.555
0.06	2.8076	1.571
0.08	2.8156	1.578
0.1	2.8208	1.583
0.12	2.8296	1.591
0.14	2.8364	1.597
0.16	2.8468	1.605

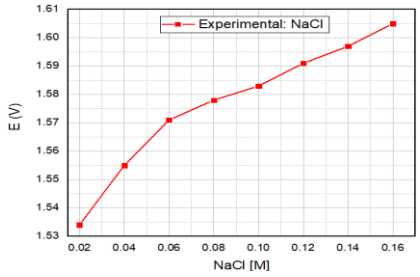

Figure 3: Experimental results with NaCl solutions.

Human sweat tests

Once sensor is able to measure electrolyte concentrations in the range normally found in human sweat (10mM/L-100mM/L), we proceeded to take measurements with a test subject during a period cycling test. After 15 minutes, the results showed stable values of up to 1,468 volts after the first 200 seconds Fig. 4. Although the electrochemical potential was decreased by approximately 1 volt compared to the results of experimental tests in the laboratory, the potential is higher than those of currently reported sensors, and this may be due to the intervention of other factors including sweat and the amount of sweat present during the reaction on the patch.

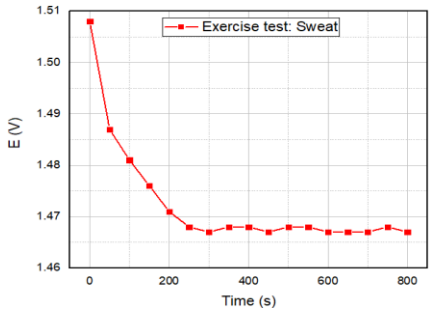

Figure 4: Test results with sweat in an exercise test.

CONCLUSIONS

A simple and low-cost sensor was built that can correctly monitor electrolytes in sweat, obtaining measurement ranges greater than 100 mM/L, electrochemical potentials greater than 1.46 volts, and electrode duration greater than 3 weeks. A more detailed mathematical analysis should be done in future work using Faraday's laws for electrolysis and the Butler-Volmer equation to optimize electrode geometry and cell design with simple fabrication techniques, to obtain optimized results in terms of electrochemical potential and electrolyte measuring range.

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