Exploitation of a pH-sensitive hydrogel for CO_2 detection

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Summary: *In this paper is described how hydrogel is exploited as sensor material for the detection of carbon dioxide (CO_2). A pH-sensitive hydrogel disc, which swells and deswells in response to pH changes, was clamped between a pressure sensor membrane and a porous metal screen together with a bicarbonate solution. Bicarbonate reacts with CO_2 resulting in a pH change. The enclosed hydrogel will generate pressure as a response to the pH change. This pressure is a measure for the partial pressure of CO_2. The main advantage of this sensor principle is the lack of a reference electrode as required for potentiometric sensors.*

Keywords: hydrogel, Pco_2 sensor, Severinghaus
Subject category: 5 (Chemical sensors) & 6 (Biosensors)

1. Introduction

Stimulus-sensitive hydrogels are cross-linked hydrophilic polymers which undergo a volume change in response to changes in stimuli, such as pH, temperature, electric field, ion concentration or light [1]. This research project aims at exploring the possibilities of detecting the pressure built-up generated by a hydrogel contained under isometric conditions for sensor applications.

2. Sensor design

The first goal is to develop a gastric Pco_2 sensor for measuring the partial pressure of CO_2 in the stomach to determine whether a person has Gastrointestinal Ischemia [2]. To realize this, a pH-sensitive hydrogel disc is used. This type of hydrogel will swell with a decrease in pH and deswell with an increase in pH. A miniature pressure sensor is used to observe hydrogel swelling. In figure 1 a schematic representation of the hydrogel-based Pco_2 sensor is shown.

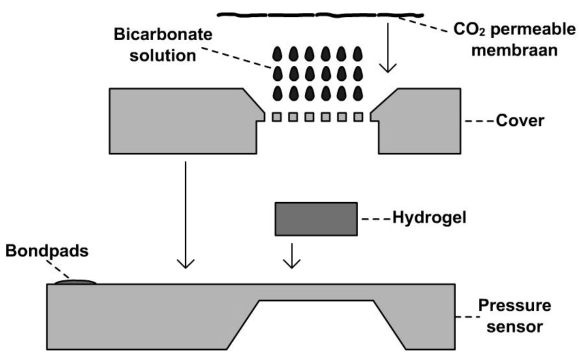

Fig. 1. Schematic representation of the hydrogel-based Pco_2 sensor.

CO_2 will diffuse through the membrane and react with the bicarbonate solution resulting in a pH decrease (Severinghaus principle [3]). In response to the pH decrease the hydrogel would like to swell, but since its volume is fixed by the porous cover (isometric conditions), a pressure will be generated. This pressure is measured by the pressure sensor and is thus a measure for the partial pressure of CO_2.

3. Experimental

The hydrogel disc was prepared from 2-hydroxyethyl methacrylate (HEMA, Acros) and 2-(dimethylamino)-ethylmethacylate (DMAEMA, Acros) by UV-polymerization. A monomer mixture of HEMA and DMAEMA was made with a mole ratio of 95:5 and to the total mole amount, 1.5% cross-linker tetraethyleneglycol diacrylate (TEGDA, Fluka) and 3% photoinitiator 2,2-dimethoxy-2-phenylaceto-phenone (DMPAP, Aldrich) was added. The solution was pipetted on a silicon mould with a cavity of 50 µm and covered with Mylar foil. On top a mask was placed with an aperture (diameter = 750 µm) through which the UV light can pass. The hydrogel was polymerized by 366 nm UV for 90 seconds. The principle is shown in figure 2. By using this method a hydrogel with a thickness of 50 µm can be made.

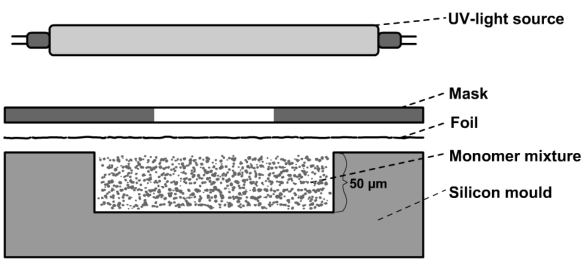

Fig. 2. Schematic representation of the setup that is used to obtain hydrogel discs with a diameter of 750 µm and a thickness of 50 µm.

The hydrogel disc was placed on the pressure sensor membrane of a bare Honeywell pressure sensor. The pressure sensor was glued on a PCB stick and wirebonded. On top of the sensor a porous metal screen was glued (for the initial experiments a metal screen was used instead of a silicon cover).

4. Results

For the initial experiments the sensor was first placed in different 100 mM pH buffers to measure the pressure the hydrogel generates as a function of pH. The result is shown in figure 3. As expected the pressure increases with decreasing pH.

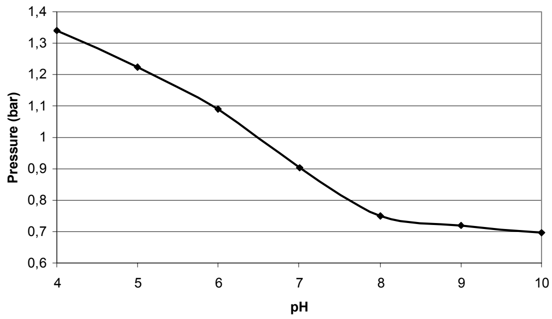

Fig. 3. Plot of the measured pressure versus pH.

Next, a CO_2 measurement was performed. The sensor was placed in a 100 mM $NaHCO_3$ solution together with a pH electrode. Gas was bubbled through the solution starting with 100% N_2, then 100% CO_2 and again 100% N_2. During the experiment the pH and pressure were measured versus the time. The result is shown in figure 4.

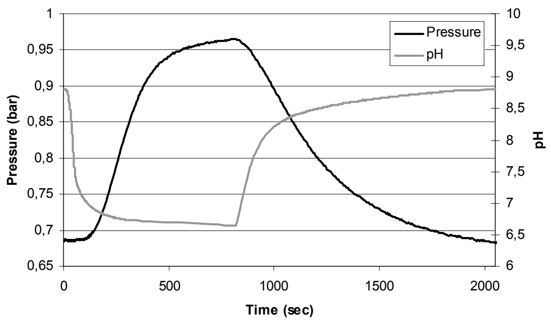

Fig. 4. Plot of the pH change of a 100 mM sodium bicarbonate solution and the pressure change of the hydrogel based sensor as result of a gasflow change from 100% N_2 to 100% CO_2 and back to 100% N_2.

As can be seen in the plot, the pH decreases first by the CO_2 and then increases again by the N_2 removing the CO_2. The pressure at start is 0.68 bar caused by the clamping of the hydrogel. At t = 800 seconds the pH is decreased to 6.7 by the CO_2. Due to this pH decrease, the hydrogel wanted to swell, but since it's volume is fixed it generates an additional pressure of 0.29 bar resulting in a pressure of 0.97 bar. By interpolating the plot from figure 3 the pressure at pH 6.7 can be found which is around 0.95 bar. This agrees reasonable well with the pressure measured during the CO_2 experiment.

Compared to the previous experiments with a Pco_2 sensor holding hydrogel microspheres, the use of a very thin layer of hydrogel gave a faster response [4].

5. Conclusions

A sensor concept is demonstrated where the swelling of a thin pH-sensitive hydrogel layer is measured with a miniature pressure sensor. With the addition of bicarbonate it is shown to be possible to measure CO_2. The principle showed in this article could also be used for other stimulus-sensitive hydrogels, such as a glucose-sensitive hydrogel to construct a glucose sensor.

References

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