Effect of Nafion Hydration on its Actuation Characteristics

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Abstract

Traditionally Nafion is actuated while being hydrated along its surface. This paper presents an investigation into the electro-active actuation characteristics of Nafion while being hydrated from one of its edges to avoid direct water contact with the surface. The effectiveness of actuation of electrically excited platinum coated Nafion cantilever past a 12 minute time period without direct hydration is investigated. While cantilever strips were subjected to pressurised water at the fixed end, both coated and uncoated Nafion actuation characteristics were investigated for amplitude and time of response. . The oscillations of coated strips were able to be sustained for more than 24 hours with the techniques used, Although there was a decrease in the amount of deflection over the time period, the results suggest that hydration of the Nafion substrate can be maintained without complete surface contact, and a platinum coated region can perform as an actuator, continuously, for longer periods than previously observed in air.

Introduction

The main objective of this work is to investigate the possibility of using a single material to perform simultaneous actuation and humidification.. The polymer material Nafion was developed by DuPont in the 1960's[1] and has been used extensively for fuel cells historically[1-6]. The Fluorine dominated backbone of the molecule allows it to be extremely selective for what permeates through the molecular structure and this allows Nafion to be used as a selective humidification material [7-11].

Millet et al [12] developed a method to coat Nafion with a thin layer of metal in order to use it as an electrode. Different metals have been used for the electrode such as Copper, Silver, Nickel, Gold and Platinum as well as other metals and combinations of metals. Different thicknesses, patterns and orientations of the electrode have been reported and the variations applied produce different effects when energised.

The electrode function allows a charge gradient to force ion migration to swell one side of the polymer preferentially over the other. This preferential swelling produces movement and actuation. When the material is in good intimate contact with a hydration source, such as water, the state of hydration is sufficient that the charge relationship will relatively quickly change the material and produce relatively quick and significant actuation, when stimulated.

Alternating current produces a peak to peak voltage that expresses itself in an oscillating motion of a cantilevered beam of the IPMC that was studied. This oscillating motion has been shown in experiments with different geometry such as discs, beams and more complex shapes such as masked patterns that are not symmetric or based on a single geometric pattern. The dispersion of the electrical energy disperses the material mechanical response of the ions in the material along the same principals as a simple beam and load. If the shape of the beam, or the energy gradient being applied to that beam varies, due to beam geometry or thickness, hydration distribution, electrode geometry or thickness of electrode, then the forces distributed to the beam, causing its motion, will be altered. When the edges of the beam are free to move, such as a cantilever, the amount of deflection and the speed of the motion are unrestrained and therefore significantly higher values are observed than in a fixed edge motion.

When the polymer material is in contact with a liquid, the hydration process is very rapid and significant. The Nafion material can remain hydrated and allow humidification to take place continuously, based on controlling factors such as temperature and flow rate, the level of humidity in the adjacent air can be altered within the boundary conditions of an experimental set up. Area of exposure, flow rates of the passing air and temperature determine the humidification of this contact phenomenon. When the Nafion is hydrated, the metal electrode effect is distinct and the IPMC material can actuate significantly as the charge oscillates the strip oscillates periodically. If the polymer becomes dehydrated, then the motion of the electro-chemical-mechanical actuation ceases.

It has been well established that when Nafion remains in physical contact with a liquid capable of hydration, such as water, the hydration easily occurs and continues at room temperature, as long as enough surface area is in contact with the surface [13].

This paper investigates different methods of Nafion hydration and study ithe effect on its actuation characteristics.

Methods and Materials

Material Preparation

Nafion 117 material was used for all the experiments in this paper.. The material was roughened using 1200 grit sandpaper, This provided a greater surface area for the platinum metal coating. The Nafion was cleaned by soaking in a 1:1 solution of HNO3:H20 solution for 1h. After this, the material was placed in a 0.1M solution of Pt(NH3)4Cl2・2H2O for a period of at least 12 hours to allow platinum molecules to adsorb into the surface of the Nafion membrane. The Nafion was then rinsed with DI water before being placed into a 4 g/L solution of NaBH4 to reduce the platinum tetramine to platinum metal. The contact time for this step was 90 minutes. Finally the sample material would be rinsed with deionised water and dried with a paper towel. Once coated with platinum, the Nafion was cut into electrode strips of the size required for each experiment. The method was used to deposit a coating of platinum that was estimated to be 1-3 microns thick

Preliminary experiments (figure 1) on uncoated and coated Nafion indicate that coated Nafion placed in intimate contact with water could be hydrated and it can transmit humidity to surrounding air.

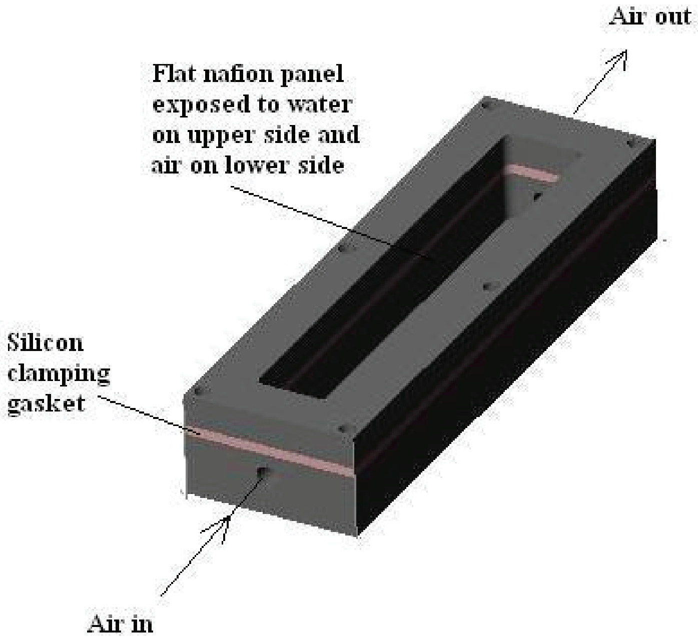

Fig. 1: Air Humidification experimental Nafion membrane holder schematic

Experiments showed that hydrated coated Nafion can be actuated and this property degrades when the Nafion is dehydrated.

Axial Hydration

Previous humidification experiments showed that the pressure on the Nafion membrane increased humidification to a certain extent. Based on these initial results, an experiment was designed to try transverse hydration where the source of the deioniesd water was pressurised by a known amount of hydraulic pressure from a standing fluid head. A water column was erected using a an inverted burette tube, filled with deionised water and with the lip edge of the inverted tube forced into intimate contact with the upper surface of the Nafion strip to be tested as shown in Figure 2. The Nafion strip was 10mm wide x 60mm long with the platinum coating covering 40mm of the strip. The exposed 20mm of uncoated Nafion was anchored with mastic adhesive on the underside of the Nafion so that the burette tube could be forced against the upper surface to form a seal of the glass against the uncoated Nafion. In this way, the glass could be positioned to allow the column of water to sit against the Nafion surface and let the pressure of the column height act against the small contacted surface. The inner surface contact was approximately 23.5mm^2 and the original height of the deionised water was 270mm.

Dry uncoated Nafion was placed under the water column arrangement described above and electrodes were attached to the top and bottom platinum coated surfaces, as close to the uncoated region as space would permit (approximately 6mm from the edge of the region). After the first 15 minute of hydration period had passed, the signal generator was turned on to generate the actuation signal. 10 Volts Peak to Peak in a sine wave pattern at a frequency of 14 Hz was used as the excitation energy for the beam. This signal produced an oscillating pattern of motion up and down that was captured using still images and video. The deflection was approximately 2 to 2.5mm in each direction from the neutral position.

Due to the gravity fed direction of the water, as the hydration source, the oscillations are up and down in the direction where self weight cannot be ignored. An ideal arrangement for the oscillating beam would be side to side to avoid the interference of beam weight in the direction of motion. Other studies have found that Nafion platinum actuation displays marked asymmetric behaviour, so this also should be taken into consideration for the direction of motion. The signal generator was run continuously for 24 hours and the IPMC beam was observed at the end of the 24 hour period. The beam continued to display actuation after the 24 hour period, although the deflection had decreased. .

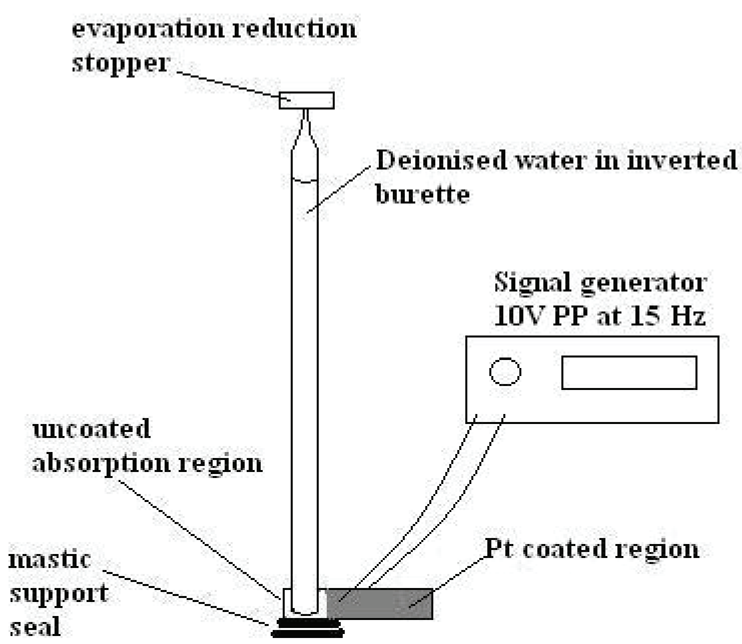

Fig. 2: Axial local surface hydration experimental set up schematic

End Covered Hydration

In this experiment, the same column head pressure was attempted to be applied to the uncoated Nafion using a different set up (Figure 3). A reservoir was built with a slit in it so that the Nafion could be edge and transverse pressurised at the same time. The Nafion was passed through the slit and sealed so that platinum coated beam was free to move and the uncoated Nafion was sticking into the reservoir. The top of the reservoir chamber had a seal so that the water column could be placed into the chamber and the pressure of the water column maintained against the Nafion edge and both sides of the untreated Nafion inserted into the chamber.

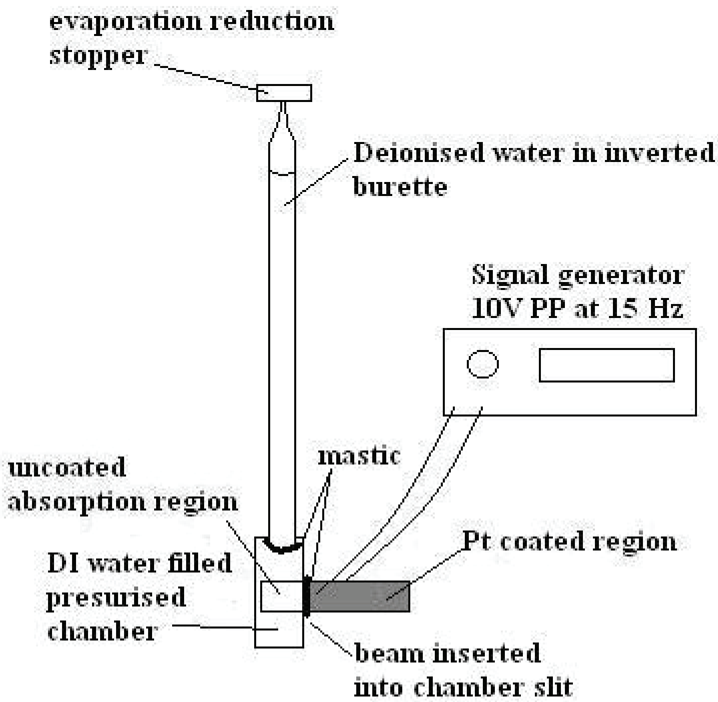

Fig. 3: End covered hydration chamber experimental schematic

The two coated surfaces were connected to the same electrodes and the signal generator as in the first experiment and allowed to hydrate for 15 minutes.

Results and Discussions

For the axial hydration, the deflection was approximately 2 to 2.5mm in each direction from the neutral position. After 24 hours of the hydration through water column pressure, the beam was still oscillating from the signal stimulation.

The amplitude of oscillation decreases to about 1mm, but the signal was still producing motion. The water in the column had dropped by 0.1cm^3

Due to the gravity fed direction of the water as the hydration source, the oscillations are up and down in the direction where self weight cannot be ignored. An ideal arrangement for the oscillating beam would be side to side to avoid the interference of beam weight. Other studies have found that IPMC actuators have displayed asymmetric behaviour, so this also should be taken into consideration for direction of motion [14].

For the end covered hydration, the Nafion beam oscillates with similar amplitude of about 2mm. After a 24 hour period, the same set up was still producing motion and as was the case of the transverse hydration experiment, the amplitude decreases to about 0.75mm. The water in the column had dropped by 0.3cm^3

The pressure of the column has enabled the material to remain hydrated enough to continue functioning as an actuator for more than 10 minutes. The functionality has diminished in performance and effectiveness, but unlike previous observations, it has produced continuous actuation for 24 hours.

Since the water column has dropped in both cases, the beam must be dispersing water into the air around it as a humidifying element, as it actuates. The volume of water dispersed is relatively small, so the mechanism of the water dispersion versus the efficiency of the actuation needs to be further investigated.

The direction of oscillation for the transverse and end covered hydration methods were up and down motion. However, oscillating the beam back and forth in a gravity neutral manner can be easily design.

Another feature of the new reservoir set up is that the Nafion member does not need to be the width of the column to form a seal. The area of contact of hydration of the uncoated Nafion relative to the coated area can be varied to suit the needs of the actuation and the humidification. The column height, and hence the fluid pressure can also be increased or decreased to determine a maximum value for either function for a given geometry of Nafion and platinum.

The pressure in one region of uncoated Nafion allows the material to be hydrated past that region and also allows electrical stimulation of the platinum metal coated region to take place without difficulty. The decay in functionality suggests that either the metal material is work hardening, or that some mechanism of transport for the water is becoming clogged or damaged through use.

Summary and Conclusion

All of our earlier experiments working on actuation used pieces of Nafion and platinum that were immersed in water until the experiment was about to be started, then quickly removed from total hydration and placed in the electrode set up and energised until they ceased to move. This period of actuation was less than 15 minutes. Upon rehydration and re-attachment, actuation functionality would return, but often in a diminished capacity and again with a failure to persist based on dehydrating in a relatively small amount of time (less than 15 minutes). This study has shown the feasibility of actuating Nafion continuously. Using axial and end covered hydration methods, the continuous actuation was achieved. However, degradation in the amplitude of the actuation was also observed.
Further work has to be undertaken to quantify the extent of water migration in the beam, to optimise pressure required for a specific geometry, electrode layout, beam geometry and direction of motion relative to gravity for purposes of humidification and actuation design of a device.

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