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PREPARATION OF AN ULTRAFAST WATER DISTRIBUTED SENSOR BASED ON POLYVINYLAMINE COMPOUNDS AND Cu(II) SALTS

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Abstract: A method to prepare cross-linked PVAm hydrogels employing a Cu(II) ion is disclosed in this work. This material is electrical insulate at its dry state, however, it changes dramatically when it enters in contact with water. This polymeric complex can be processed by co-extrusion and employing to assemble distributed water sensors. Its capacity for sensing and pin-pointed water leakage is validated.
Keywords: Water, Distributed sensors, Leakages.

INTRODUCTION

The question of water economy is becoming a critical problem in urban centers and in agricultural districts due to the increasing shortage of this essential resource (1-6). Specially, leakages from water pipes are the object of much attention from administrations and companies in charge of water supply. However, considerable efforts are still necessary to ensure adequate water supply to the population.

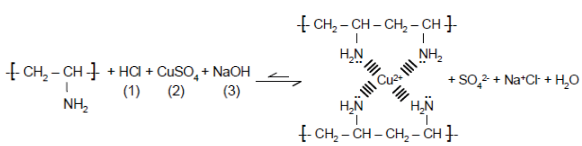
Among many similar examples, the case of Mexico City is interesting since the loss of water through leakages in this capital is about 25 % of the total amount of the water consumption. Of course, similar problems are worldwide, and them have received insufficient attention in the past. Due to the dramatic water shortage in many regions of the world, the development of efficient water leakage sensors become a high-priority issue.

In order to safeguard an extensive network of water pipes, a "distributed" design is a cheap and reliable solution for the detection and pin-pointing of water leaks. A linear sensor is placed along the pipe that contains: i) A polymeric material whose electrical properties change when it enters in contact with water, ii) an electrical conductor that senses the change in the material property and, iii) a distant monitoring system that measures the position of electric perturbation. When a leak occurs near the sensor, water permeates into the material and its electrical resistance drops. This effect triggers an alarm which warns the monitoring system that a leak has occurred and alerts of a leak.

In order to produce sensors as the ones described above, Poly (vinyl amine) (PVAm) hydrogels can be currently employed. Poly (vinyl amine) (PVAm) is a polymer with interesting properties for those purposes. Indeed, when softly cross-linked PVAm becomes a hydrogel that is capable of absorbing a large quantity of water without dissolving. This polymer can be cross-linked employing a method based on a chelating reaction with copper ions. The coordinated covalent bonds formed between the Cu2+ ions and the amine groups of PVAm produce chain junctures that conferee it certain properties such as: i) significant swelling upon water absorption, ii) resistance to dissolution in water, iii) ability of extrusion processing, iv) excellent thermal and chemical stability and, v) low electric resistivity in the wet state. We have taken advantage of those properties to design distributed water sensors with ultra-fast response, which may be utilized for the detection of leakages along water pipes, as well as to monitor places that must be free of water leaks as; libraries, electrical control centers, boats, ships, submarine facilities, etc.

EXPERIMENTAL

The material sensor is constituted by a polymer complex PVAm – Cu and glycerol is included as plasticizer, the copper ion is functionally cross-linked in accordance to:



Various formulations with different Cu^{2+} ion content were characterized (Table 1) by potentiometric titrations, FTIR, and swelling kinetic was assessed.

Formulation	PVAm matrix	%(w/w) crosslinking Agent	1,2,3 Propanetriol plastizicer	of amine groups cross-linked L_{Am}
A	15.61	0.07	5.2	0.015
B	15.9	0.25	5.3	0.05
C	15.51	0.49	5.17	0.1

Table1. Formulations characterized and used as raw material in processing of distributed water sensors.

The material was processed by co-extrusion and distributed water sensor was assembled (Figure 1). Water response and location essays for distributed water sensor were realized employing Agilent multimeter, electrical circuit and algorithm based in Ohms law.

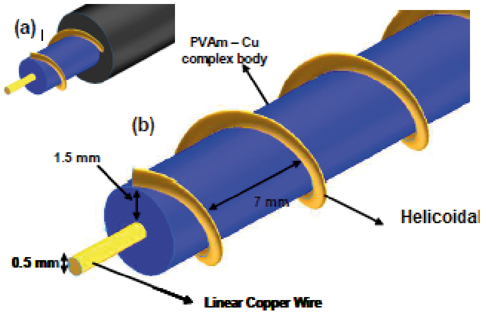


Figure 1. Distributed water sensor prepared.

RESULTS

A great and fast fall of resistance was observed (Figure 2) in formulations with low, crosslinking degree. For cupric sulphate contents of 0.07 and 0.25 wt% is observed that the fall on resistivity is very fast, the resistivity of the polymer passing in about 2 seconds from a high value in the dry state to a very low value in the wet state. By contrast the sample corresponding to a content of $CuSO_4$ of 0.49 wt% shows not only a somewhat slower kinetics, but also a limitation of the resistivity drops at 60 % of the initial level. This behavior is evidently due to the water difficulty to penetrate into a higher cross-linked PVAm / Cu(II) network.

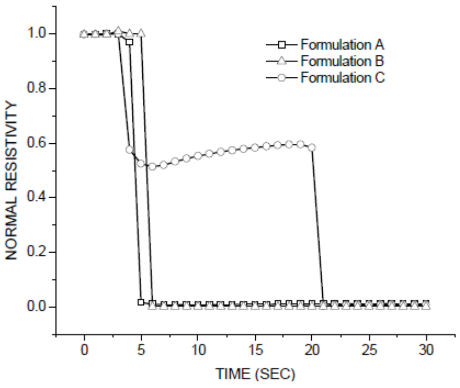


Figure 2. Electrical Response of PVAm - Cu complexes with various quantities of crosslinking agent.

Figure 3 shows the precision in pin pointing tests, when distributed sensor is exposed to water in various points along of its length, and formulation A is employed. The uncertainty is close to ±30 cm, showing great capacity for localize water leakages with a fast response.

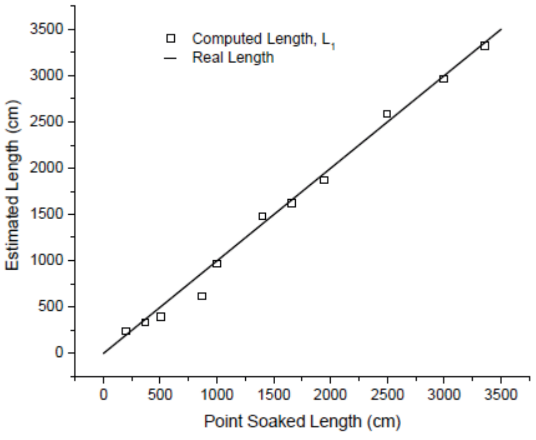


Figure 3. Location essays for distributed water sensor processed with PVAm – Cu complexes (Formulation A).

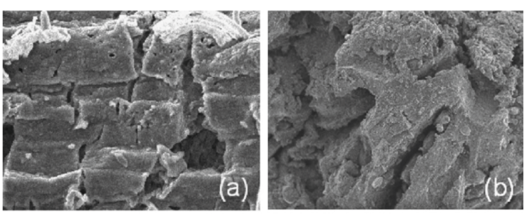
DISCUSSION

We have developed a methodology to reticulate PVAm using a copper salt. This methodology provides a material that has a cross-linking degree tough enough to be employed in water sensors, but not so strong to make it impossible to be extruded. Indeed, this characteristic permit us to fabricate a cable by extrusion, at its rubber state, but that becomes cross-linked when it is cooled at room temperature.

The hydrogels developed have an ideal micromorphology and structure which switch very fast from an isolate material to a conductive one when they enter in contact with water. Figure 4, shows micro photographs of the surfaces of each composition tested. It is appreciated that al the samples have a large porosity that permits the rapid absorption of water inside the sensor.

The complex bonds formed between the Cu(II) ions and the amine groups of PVAm produce an interesting network of crosslinked structures that generate a micro porous morphology when the material is extruded.

This characteristic and the fact that this material swells notably by absorbing water are responsible for its fast electrical switch in presence of humidity.



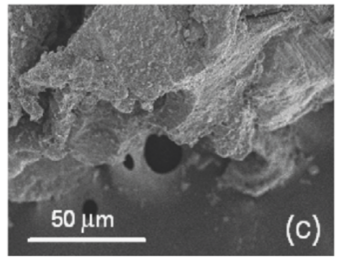


Fig. 4. SEM photographs of samples surface: (a) formulation A: 0.07 wt% $CuSO_4$, (b) formulation B: 0.25 wt% $CuSO_4$, and (c) formulation C: 0.50 wt% $CuSO_4$.

The sensor prepared has a response time close to 5 seconds, which is shorter than typical sensors, which have a response time among 1 and 5 minutes, this characteristic is important to design water sensors for any special applications. Consequently, this material is an excellent candidate to produce ultrafast water sensors.

CONCLUSION

The developed sensor presented characteristics far superior to similar sensors. Making it an excellent candidate for various industrial, urban and agricultural applications.

In particular, its response speed is notably higher than other alternatives on the current market.

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