Aplication of IPMC materials to a fluid displacement device

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***Abstract*— This thesis tackles the characterization of a mechanical device that uses a membrane made out of an ionic electroactive material IPMC (Ionic Polymer Metal Composite), that will work as an actuator whose control allows the conversion of electrical power to mechanical power. The resulting work follows on the other papers of the Energy Department on the electromechanical actuators as membranes in pumping devices and electrical captors based on ionic polymers IPMC. For this essay, two sets of laboratorial experiences were conducted in order to characterize the functionality of the membrane of the electroactive material IPMC, regarding it's performance in the displacement of the fluid inside a container. For this end:**

- **device with the IPMC membrane without encapsulation;**
- **device with the IPMC membrane totally encapsulated by dielectric gel.**

For this study, the evolution of the voltage and current on the IPMC membrane during it's performance and the flow speed of the fluid through the test canal, were taken into account. In both experiences, the IPMC membrane was impregnated on the electrolytical solution, in order to make the power conversion processpossible. So that the applicability of the IPMC actuator is verified, the experimental results were compared with its respective electromechanical model.

***Index Terms*— Artificial Muscles, Displacement, Electroactive Materials, Fluid, IPMC, Ionic Polymer-Metal Composite**

I. INTRODUCTION

The ensemble of materials designated as "active materials" are those that, in response to an electric or mechanical stimuli, alter its properties. The interest in the application of this kind of materials to electromechanical systems has shown a significant increase in the last decade, not only for the technological improvement and more competitive prices, as seen in piezoelectric and magnetostrictive materials, but also for the development of new active materials. Meanwhile, it's important to note that the physical phenomena in which most of these materials operation is based is known since the 19th century.

In anglo-saxon literature, the terminology applied to these materials is quite diverse, with terms such as: "functional materials" [1], "intelligent materials" [2], "smart materials" [3], "adaptive materials" [4], "stimuli responsive materials" [5], and "active materials" [6]. However, describing these materials as intelligent, functional or adaptive is not, according to the author, the most accurate terminology regarding their characteristic operation. With this in mind, the two latter designations, "stimuli responsive materials" and "active materials", are the most accurate, the last one being the terminology that will be used in this essay, active materials.

Active materials can be classified according to the type of electrical stimuli they react to. Therefore, the electroactive materials (activated by the electrical field), such as ceramic piezoelectric materials [7, 8], electro-rheological fluids [9], and ionic electroactive polymers - IPMC [10,11] are pointed out. Analogously, there are magnetoactive materials (activated by the magnetic field) such as magnetostrictive materials [12] and magneto-rheological fluids [13, 14]. It's still possible to point out active materials that react to temperature (thermoactive [15]), to pH [16], as well as to light (photoactive [17]).

There is a dichotomy between IPMC and the piezoelectric material PZT (Lead Zirconate Titanate). The two materials show significant differences regarding mechanical and electric characteristics, differences that relate to the magnitude of the electrical signals used as stimuli, to the magnitude of the mechanical deformations that can be obtained and also to the mechanical forces that can be produced by each one.

Depending on the application, this strain of IPMC electroactive materials may have some advantages over conventional mechanical, hydraulic and pneumatic actuators, as these do not include movable parts and require lower levels of voltage/current (~V; ~mA). The research carried out on the physical phenomena related to the understanding of the electromechanical behaviour of the IPMC material has allowed significant progress on the increase of the force produced by the material [19,20] and has also allowed for the lengthening of its operational life without any deterioration in its performance [21-23]. The capabilities of this new material are currently being explored in the development of new biomedical devices [24, 25], micro-electromechanical systems [26, 27], as well as in robotic systems that have to be light and flexible [28].

It is, therefore, in this context, that the present essay deals with ionic electroactive materials - IPMC, namely, its application in electromechanical systems.

II. IPMC ELECTROMECANICAL MODEL

The operating principle of ionic electroactive materials IPMC is based on the interaction of two parts: the mechanical, the result of which mechanical stresses within the polymeric matrix caused by external pressure; but also results electrical forces acting on the negative ionic charges fixed in the matrix itself; and the electrical part, which results from the distribution of positive ionic charges within the IPMC and the resulting electrical power density.
The electrical model and mechanical developed in [30] allows you to obtain and analyze the performance and material of the electroactive material IPMC behavior.

III. EXPERIMENTAL PROCEDURE

Two sets of experiments are performed with the IPMC device in the displacement fluid. The first set of experiments consists in the use IPMC actuator inserted into the test channel without this being encapsulated; the second set of experiments, when the surface of the IPMC actuator dielectric gel is applied so that it is completely encapsulated before inserting into the test channel. In both experiments the IPMC membrane before use, was previously hidrated in electrolyte solution - propylene carbonate with litium ions.

A. Experimental Setup

Fig. 1 shows the platform used to perform the experiments in the study. This platform is constituted by a test channel with two sections, larger and smaller. Water is deposited in the channel, and to observe its displacement and velocity imposed by IPMC device, a floating device was used.

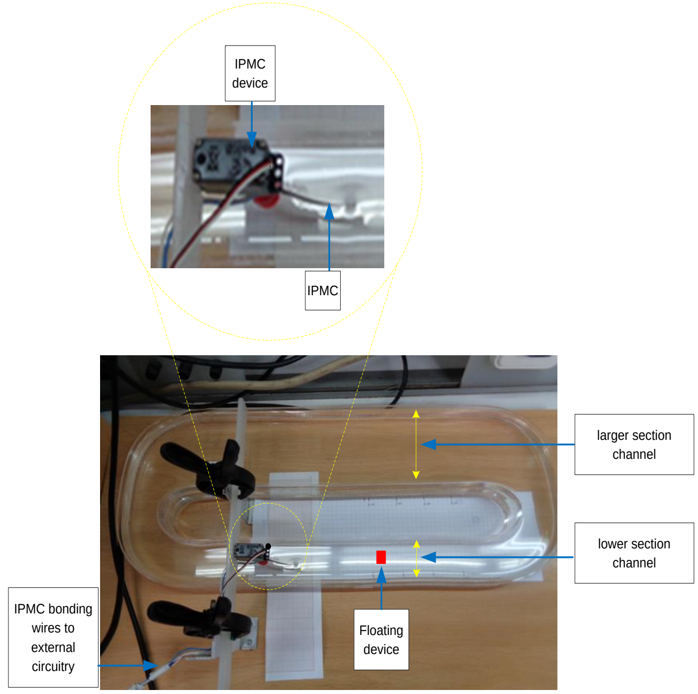

Fig.1 – Experimental platform.

Fig.2 shows the moving direction of the fluid, identified by movement of the floating device.

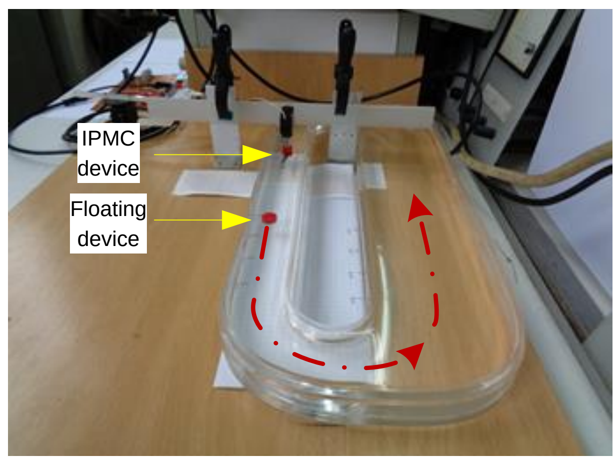

Fig.2 - Movement of the floating device in the channel.

Fig.3 shows the arrangement of the floating element in the channel to traverse a length of 9 cm. To get a more accurate measure of the average time it takes the fluid to go 9 cm indicated along the canal, it was divided into three spaced intervals of 3 cm each.

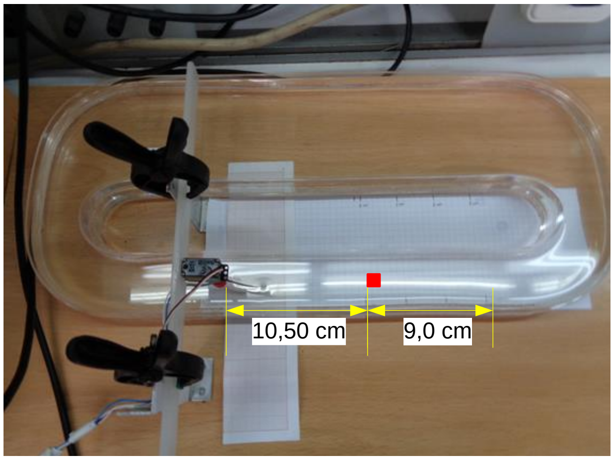

Fig.3 - Disposition of the floating dispositive in the channel to move the distance of 9 cm.

B. First Experimental Results: IPMC operation without encapsulation

The values for the time that the fluid driven by the IPMC device takes to reach the distances study (3, 6 and 9 cm) are reported in Table I as a function of command often the IPMC is excited. Fig.4 thus shows for each interval (3, 6 and 9 cm) and the estimated flow velocity of the respective frequency when applied external sinusoidal voltage of 15V.

TABLE I

IPMC without encapsulation.

Freq [Hz]	**0,1**	**0,2**	**0,3**	**0,4**	**0,5**	**1**	**1,5**	**2**
$Time_{3cm}$ [s]	53	26	36	19	12	12	19	29
$Time_{6cm}$ [s]	27	27	22	22	15	13	16	28
$Time_{9cm}$ [s]	26	25	21	18	14	13	16	26

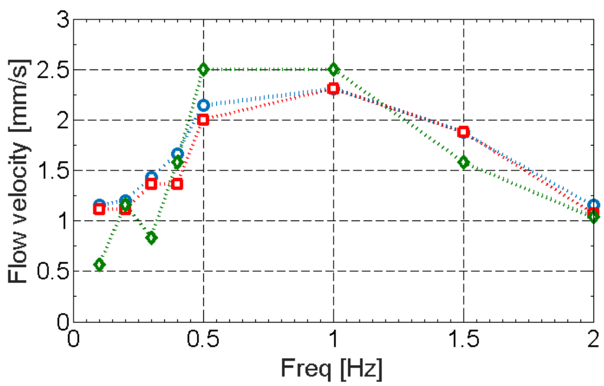

Fig.4 – Estimated flow velocity versus frequency for each interval (3, 6 and 9 cm).

From the results, it is verified for all the intervals IPMC device has a cutoff frequency from 0.5 Hz. This value is related not only to the dimensions and mechanical characteristics of IPMC used but also with the characteristics of the fluid to be displaced (water in this case).

To verify after how much time the electrolytic solution (propylene carbonate with lithium ions) impregnated in the strip IPMC maintains, or not, its properties during operation of the immersed device in water, there were five behavior registers at intervals of time 20 to 20 minutes. For each interval of time and always with the IPMC device operation was performed to measure the fluid displacement driven by IPMC time to a distance of 6 cm. The values calculated for the flow velocity are listed in Table II.

TABLE II

IPMC behavior without encapsulation as a function of time relative displacement in the fluid during periods of 20 minutes at the distance of 6 cm.

	Fluid velocity to reach the distance of 6 cm [mm/s]	**Time intervals in periods of 20 minutes [minutes]**
1	1,43	20
2	1,58	40
3	1,58	60
4	1,58	80
5	1,54	100

Fig.5 shows the evolution of the flow velocity over the 120 minutes that the IPMC device worked without interruption.

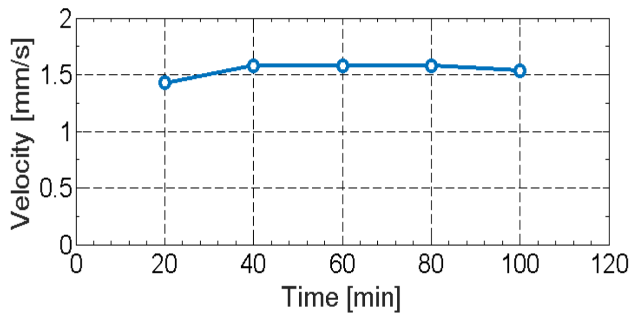

Fig.5 - Fluid velocity over time.

By analyzing the graph of Fig.5, it is observed that the velocity of the fluid remained nearly constant for the considered time intervals up to 120 minutes. Given these results, it is concluded that the properties of the electrolytic solution impregnated in IPMC strip were not changed over time in the study, thus maintaining a constant performance in the displacement fluid.

To verify the evolution of the voltage and current in the actuator IPMC over 120 minutes running time, 40 to 40 minutes was measured amplitude of the current signal imposed on the IPMC device, was measured amplitude of the voltage induced to IPMC terminals and, finally it calculated the value of the flow velocity of the fluid at a distance of 3 cm.The values are listed in Table III.

TABLE III
Voltage and Current in IPMC.

	Current [mA]	Voltage [V]	Velocity [mm/s]	Time [minutes]
1	64	3,2	30/46,2	40
2	66	3,1	30/24,2	80
3	67	3,0	30/19,0	120

In the following Table III, Fig.6(a) allows to observe the evolution of the flow velocity of the fluid displaced by the IPMC device.

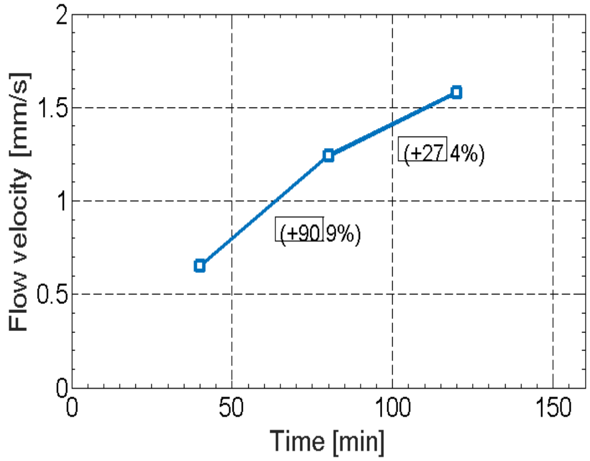

Fig.6(a) - Evolution of the flow velocity of distance of 3 cm over 120 minutes run time.

The graphical analysis of Fig.6(a), there is the fluid displaced by the IPMC materials takes to drain the first 40 minutes to reach the distance of 3 cm. The reason for this delay is due to the fluid that was initially at rest and, after being imposed to the control conditions IPMC device, it will drive the fluid allowing for this movement there is in the tank. The reason for the decrease of the time the fluid takes to reach a distance of 3 cm obtained in the 2nd and 3rd register, increasing the flow rate in Fig.6(b), is due to the fact that from the 1st recording and taking advantage kinetic energy of the fluid driven by the IPMC device, the average speed at which it circulates in the vessel gradually increases to reach a constant value.

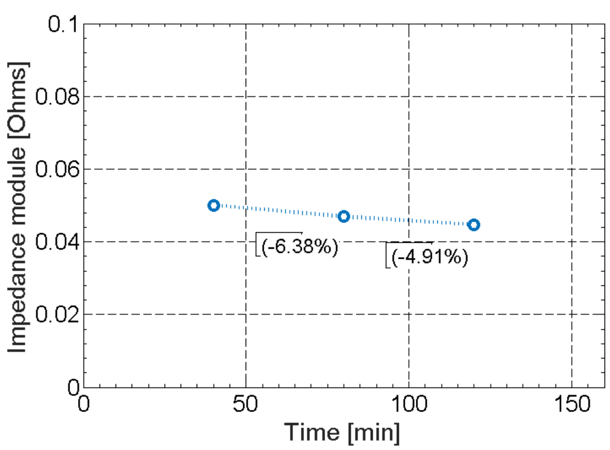

Fig.6(b) - Evolution of increasing the flow velocity of the fluid over time 120 minutes.

C. Second Experimental Results: IPMC encapsulated

Encapsulation of IPMC membrane consisted in applying a dielectric layer of gel DOW CORNING® 3-4154 across the strip, in order to avoid evaporation of electrolyte or contamination by the fluid to move. There have been many experiments regarding the performance of the IPMC material in the displacement fluid, having been pre-hydrated in 24 hours electrolytic solution of propylene carbonate with lithium ions.

For external sinusoidal voltage 15V applied to the values relative to the time the fluid displaced by the IPMC device takes to achieve the distances (3, 6 and 9 cm) are shown in Table IV. Moreover, the function of displacement speed command frequency is shown in Fig.7.

TABLE IV
IPMC encapsulated

Freq [Hz]	0,1	0,2	0,3	0,4	0,5	1	1,5	2
$Time_{3cm}$ [s]	135	124	115	124	128	133	139	135
$Time_{6cm}$ [s]	126	143	117	129	127	132	142	131
$Time_{9cm}$ [s]	127	148	120	123	129	129	140	134

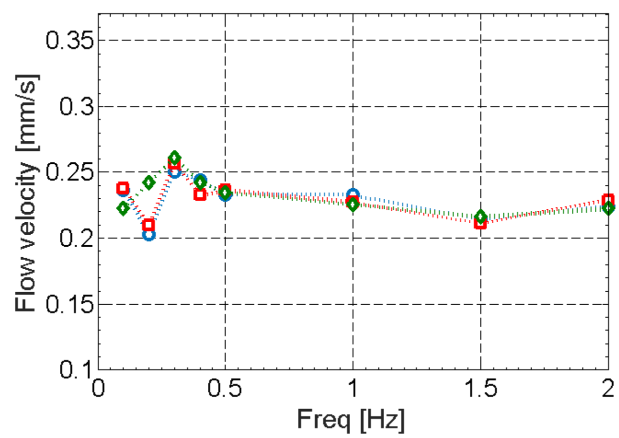

Fig.7 – Estimated flow velocity versus frequency for each interval (3, 6 and 9 cm).

Observing the evolution of the values for the flow velocity in Fig.7, it is found that it takes an average value that remains between 0.15 to 2 Hz. The results also point to a cut on frequency of about 0.3 Hz, the lower value of that obtained without encapsulation (0.5 Hz), because the mass of the device IPMC increased due to encapsulation.

In order to determine the variations in fluid velocity displaced by IPMC encapsulated strip and running over a time period, performed six registers values with 40 minute time intervals up to the end time 240 minutes of operation.

The six values are listed in Table V, while flow velocity values are represented in Fig.8.

TABLE V
IPMC encapsulated in function of time relative displacement in the fluid during periods of 40 minutes at a distance of 3 cm.

	Time the fluid takes to reach a distance of 3 cm [s]	Time intervals in periods of 40 minutes [minutes]
1	132	40
2	125	80
3	133	120
4	125	160
5	128	200
6	140	240

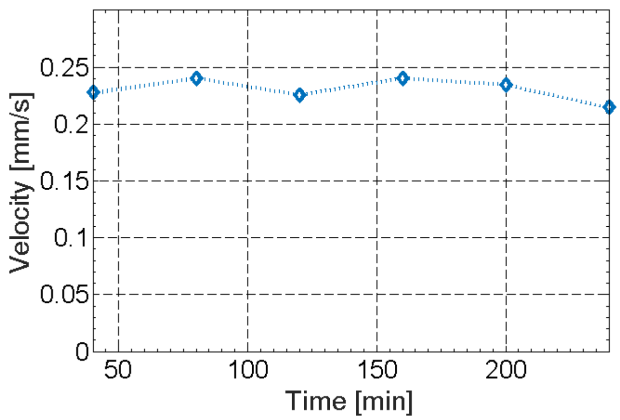

Fig.8 - Fluid velocity over time.

By analyzing the graph of Fig.8, it can be seen that the velocity of the fluid remained practically constant over the time period under study, i.e followed 4 hours of operation.

The evolution of the voltage and current in the actuator IPMC over 240 minutes running time, 40 to 40 minutes was measured amplitude of the current signal imposed on the IPMC device, was measured amplitude of the voltage induced to IPMC terminals and, finally it calculated the value of the flow velocity of the fluid at a distance of 3 cm.The values are listed in Table VI.

TABLE VI

Voltage and current in IPMC.

	Current [mA]	Voltage [V]	Velocity [mm/s]	Time [minutes]
1	42	3,8	30/132	40
2	38	3,7	30/125	80
3	22	4,5	30/133	120
4	17	4,7	30/125	160
5	16	5,0	30/128	200
6	14	5,3	30/140	240

Following Tables V and VI, the graphs of Fig.9(a) and Fig.9(b) allow to observe the evolution voltage, current in IPMC strip and the fluid velocity over the operation period corresponding to the six made registers.

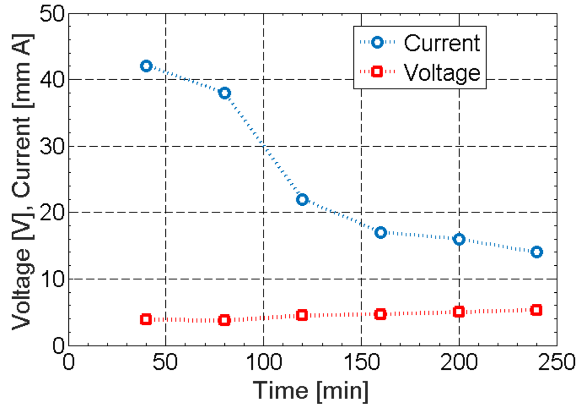

Fig.9(a) - Evolution of Voltage, Current over time in IPMC

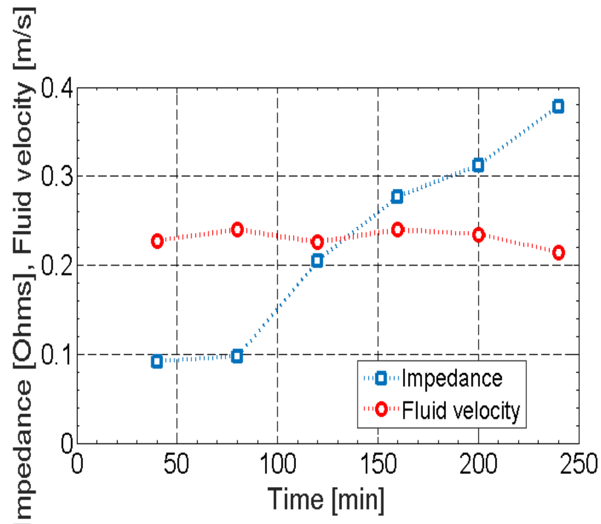

Fig.9(b) - Evolution of increasing the flow velocity of the fluid over time 240 minutes.

IV. Conclusion

The experimental results regarding the performance of the device in IPMC displacement fluid, when the strip is encapsulated or not, to conclude that despite the fluid being water could have been any other fluid, IPMC response to external commands applied when it is prompted

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