ELECTRICAL-INDUCED FLOW IN PVA/AA HYDROGEL MICROCHANNELS

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Abstract- The need to study flow through micropump has led to wide investigation on microfluidic devices. Although several investigations have been reported on different microfluidic, this work was design to investigate electrical induced flow in a hydrogel microchannel at varying hydraulic diameters. A semi interpenetrating polymeric network method was used to synthesize hydrogel, which was a crosslink of polyvinyl alcohol and acrylic acid. Other reagent used to form at varying proportions are hydrogel are (HCL, $(NH_4)_2S_2O_8$,$C_5H_8O_2$ and $C_6H_{16}N_2$). Polymeric hydrogels were formed at a ratio of 39 : 61%,50 : 50% and 60 : 40% polyvinyl alcohol to acrylic acid. Micromechanical characterization was conducted on the polymeric hydrogel. The pre-polymer solutions of hydrogel were poured on PMMA mold to form a microchannel of hydraulic diameter 800µm, 1000µm, 1200µm and 1400µm respectively. Flow investigation was carried out with water as working fluid at an applied voltage of 2V to 22V,with microchannel power consumption of (0.80W-165W) for 800µm,1000µm,(1.80W-176W) for 1200µm and (1.98W-180.40W) for 1400µm hydrogel microchannel respectively. The hydrogel Microchannel performance was compared to literature. The 39:61% PVA/AA crosslink hydrogel under applied load of 5.8210N deformed at 0.60260mpa and break at 0.42152 MPa to give a young modulus of $(-0.80 \text{ to } 1.01)N/M^2$.The 50:50% crosslink PVA/AA hydrogel under applied load 2.37762N deformed at 0.24441MPa and break at 0.08213 MPa resulting in a young modulus $(-7.0 \text{ to } 1.0)N/M^2$.The 60:40% PVA/AA hydrogel crosslink with distill and ionized water under applied load 3.41912N,deformed at 0.05422mpa,result in young modulus $(-4.0 \text{ to } 1.0)N/M^2$; and at applied load of 2.14706N,breaking point was 0.00587mpa result in young modulus $(-3.50 \text{ to } 1.10)\ N/M^2$. The performance efficiency for hydrogel microchannel of hydraulic diameter 800µm,1000µm,1200 µm and 1400 µm with different crosslink ratio were (0.00% to 32.96%)PVA/AA 39:61%,(0.00% to 26.22%)PVA/AA 50:50%,(0.00% to 217.3%)PVA/AA 60:40% and (0.00% to 349.48%)PVA/AA 60:40% hydrogel crosslink with ionized water at a flow rate of (0.00ml/min to 0.18ml/min)800µm,(0.00ml/min to 0.32ml/min)1000µm,(0.00ml/min to 0.47ml/min)1200µm and (0.00ml/min to 0.50ml/min)1400µm. This study established that with increase in hydraulic diameter of PVA/AA hydrogel microchannel there will be increase in flow rate and consumed low power. The hydrogel microchannel can also serves as an alternative to micropump which could be applicable for design of feeder systems for cleft deformities.

Keywords- Hydrogel, Microchannel, Microfluidic, Polyvinyl Alcohol, Acrylic Acid, Polymethylmetalcrylate

I. INTRODUCTION

Hydrogel is a form of material generally constructed by hydrophilic multiphase polymer mixtures that may exhibits both solid-like and liquid like properties. Its structural framework is formed from three-dimensional network of randomly cross-linked polymeric chain that embodies three different phases, namely solid polymer networks matrix, interstitial water or biological fluid and ion species (Chippada, 2010). The solid structure portion of the hydrogel is a network of cross-linked polymer chains where their three dimensional structure is usually described as a mesh with interstitial space filled up with fluid, the meshes of networks holds the fluid in place and also impart rubber like elastic force that can compete with the expansion or contraction of the hydrogel, thus providing the solidity of hydrogel (Tibbitt and Anseth, 2009). Electrical induced flow through a hydrogel microchannel is a crucial alternative to use of micro-pump since hydrogel has been reported to exhibit properties that predisposed it as candidate polymer for fluid transport applications (Ige et al., 2017; Raj et al., 2017).

In the development of hydrogel-based microfluidic devices, an important issue is to downscale the hydrogel size up to micro- or nano-meter scale. This enables not only to obtain components with size comparable to that of microchannel, but above all to overcome the diffusion limitations suffered by larger hydrogels. Indeed, the hydrogel response is typically driven by diffusion of ions and molecules through the polymer network, according to the Donnan equilibrium. The time scales for the volumetric change is highly dependent on the distance of diffusion or the size of the hydrogel, therefore a decrease in hydrogel size at the micro/nano scale can enhance the hydrogel response time up to few seconds or sub seconds, (Eichenbaum, et al., 1998; De, et al., 2002; Simona, et al., 2012) with interesting applications in microfluidic device (Peppas, et al., 2006; Simona, et al., 2012). Smart polymers have been essentially deposited as thin films (see Tokarev and Minko, 2009) and colloidal particles Malmstadts, et al., 2003; Malmstadt et al., 2004; Peterson, 2005; Simona, et al., 2012) on solid surfaces for microfluidics. Hydrogel structures have been mainly patterned using photolithographic approaches similar to those employed in semiconductor industry (Seong, et al., 2002; Ebara, et al., 2006; Khademhosseini and Langer, 2007; Simona, et al., 2012).On the other hand, colloidal particles is excellent candidates for

the fabrication of stimuli-responsive surfaces and coatings. A great variety of applications would ideally take advantage of the unique properties of such smart surfaces. Some examples include microfluidic flow control, (bio) sensors, micro scale chromatographic separation, solid-phase extraction, biological assays, and cell culture.

Based on electrical composition, hydrogels may be categorized into four groups on the basis of presence or absence of electrical charge located on the crosslinked chains: non- ionic (neutral); ionic (including anionic or cationic); amphoteric electrolyte (ampholytic) containing both acidic and basic groups; zwitterionic (polybetaines) containing both anionic and cationic groups in each structural repeating unit. There is a considerable variety of materials in either naturally existing or synthesizing, swellable hydrated polymeric gels. Crosslinked guar gum and collagens are the examples of the natural polymer that are modified to produce hydrogels. the synthetic hydrogels include N-isopropyl acrylamide (NIPA), poly(acrylic acid) (PAA), poly(acrylonitrile) (PAN), poly(acrylamide) (PAM), poly(acrylonitrile)/poly(pyrrole) (PAN/PPY), poly(vinyl alcohol) poly(acrylic acid) (PVA–PAA), poly(hydroxyethyl methacrylate) (Ahmed, 2015).

Micropumps have been shown to exhibit remarkable performance in terms of high flow rate greater than 1ml/min and simple fabrication. A silicon micro pump was developed for a disposables during delivery system, the pump chip demonstrate linear and accurate five percent characteristics for rates up to 2ml/h with intrinsic insensitivity to external condition (Didier, et al., 2001). From biology and medicine to space exploration and microelectronics cooling, fluid volumes on the order of a milliliters to the volume contained in cube 1cm on a side and below it on the other side, prominently in an increasing number of engineering systems. the small fluid Volume in this systems are often pumped, controlled or otherwise manipulated during operation; for example, biological samples must not be moved through a miniature assay systems (Khandumina et al, 2000; Taylor et al., 2003; Laser and Santiago, 2004). In piezoelectric inject prints heads, chambers actuation results from lateral strain induced in piezoelectric disk while in induction electro-hydrodynamics pumps, charges is induced in an inhomogeneous working fluid through the application of a potential difference across the fluid. this can be achieved with an electric field with a component transverse to the flow direction, the electrodes are then activated in a travelling wave configuration and axial components of the electric field result in a net flow (Laser and Santiago, 2004). Micropump is a MEMS definition of miniaturized pumping devices fabricated by micromachining (see Abhari, et al., 2012). In order to developed a micropump, several technology have evolved which help in giving system specification and requirements to produced different micropumps.

Bassetti, et al., (2005) developed a high-speed electrically triggered hydrogel actuator. It would be advantageous to isolate the fast, osmotic pressure-based mechanism from the slower, pH-based mechanism. The simplest way to do this is by forcing fluid flow in the microchannel: ion migration in- side the hydrogel is mostly unaffected while the H^+ and OH^- created at the electrodes is swept away by the flow. Additionally, the O_2 and H gas created is also carried away. Doing this, hydrogels are free to continue their expansion due to ionic gradients and osmotic pressures, and are not affected by any bulk changes in fluidic PH. Initial tests with fluid flow were unsuccessful because gas bubbles were not effectively driven away by the flow. To remedy this, the completed device is placed in 70 W, 50–100 motor oxygen plasma for 15 s.

In this study hydrogel based micro-sized channels is to be fabricated from synthesized pre-polymer solution, and characterized, thereafter experiment shall be undertaken to study flow of fluid by electrically inducing the Microchannel. The aim of this project is to carry out the experimental investigation of flow in an electrically induced microchannel.

II. METHODOLOGY

In pursuing the objective of this research, one may commence by critically observing and identifying the material to be used. PVA (polyvinyl alcohol); Acrylic acids Ammonium persulfate 1, 4-Diaminobutane (tetramethylenediamine); Hydrochloric acids; Glutaraldehyde solution; Grade I, 25% in H_2O, specially purified for use as an electron microscopy fixative Sodium hydroxide. The equipment used for this study are: hot plates/burner; petri dishes; pipettes; round bottom flask; beaker; electric weighing balance. The procedure used for synthesis of the polymeric hydrogels involved dissolving polyvinyl alcohol in distill water, heating using burner for between 1hrs -6hrs; thereafter adding gluteraldehyde to the resulting solution from the heated polyvinyl alcohol, and hydrochloric acid to the solution and then heating to 75℃ for 30 minute. Interpenetrating polymeric network was done by adding Acrylic acid to the solution, then ammonium persulfate, tetramethyletheldiamine and gluteraldehyde were added to the solution one after the other and left for 24hrs -72hrs. The produced hydrogel was used to fabricate a microchannel using the mould in Fig. 1(a). The experimental sey up using the fabricated channel is shown in Fig. 1(b). As shown in the set up, electric voltage is applied to the wall of microchannel which is immersed in water inside a beaker. For varying voltage, the rise of water inside the channel was observed.

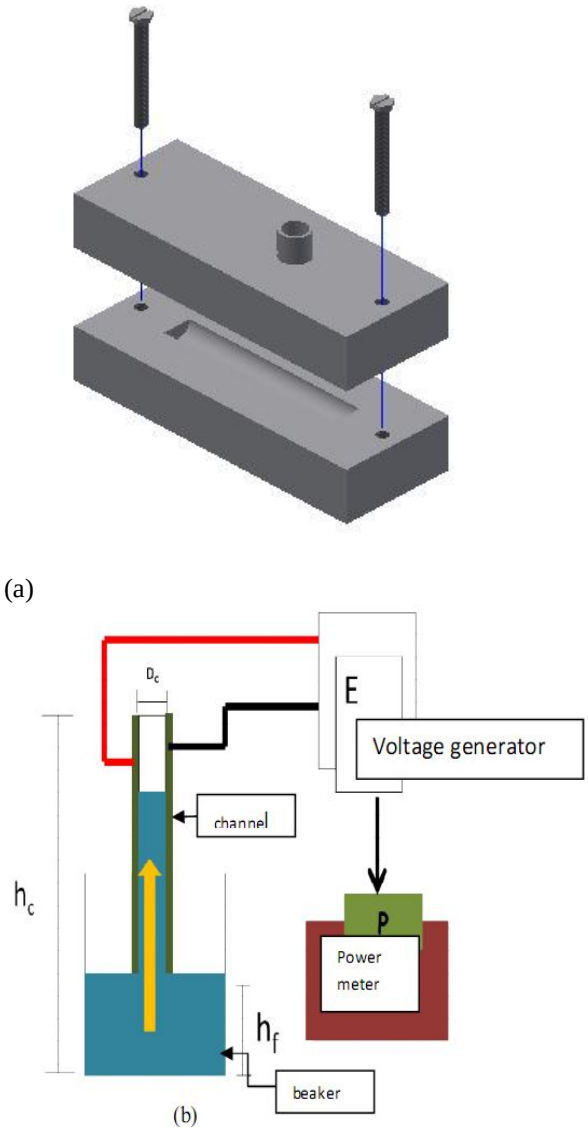


Fig. 1: (a) Mould for fabricating the microchannel (b) Schematics of Experimental Set of Micropump Upward Flow Action

Then the power used to transport fluid was calculated using Eqn. (1)

$$P = IV \qquad (1)$$

Where I is the current used to drive the flow of fluid and V is the applied voltage.
The efficiency of the hydrogel microchannel (η) acting as a pump is derived from Eqn. (2)

$$\eta = \frac{\rho g Q H}{IV} \qquad (2)$$

where ρ density of water, g is gravitational constant, Q is the flow rate and H is the height of fluid in (ml)
In assessing the performance of the developed polyvinyl hydrogel microchannel the following graphs were analysed:

(i) Graaph of Power consumed against fluid drop in the beaker
(ii) Graph of Efficiency against power consumption
(iii) Graph of Power againstfluid rise in the channel
(iv) Graph of Applied Voltage against fluid drop in the beaker
(v) Graph of Applied Voltage against height of fluid in the channel

III. RESULTS AND DISCUSSIONS

Discussion for Upward Flow Propulsion in Microchannel with a crosslink ratio of 39:61% and Hydraulic Diameter of 800µm
On application of 2V—6V there was no traces of fluid flow, as the volume of water in the beaker still remain at 200ml. On application of higher voltage (8V-18V) there was a drop in water level in the beaker as water traces occur at the outlet of the channel. When the voltages increases the flow also increases.
Fig 2 depict the graph of power against the height of fluid in the beaker; as power increases there was a considerable drop in the height of fluid in the beaker.When the volume of water inside the beaker dropped to 196.40ml power consumed was 165watts. Fig 3 is the plot of height of fluid inside the channel against voltages for channel with hydraulic diameter 800µm. On application of 2V-6V there was no flow through the channel but at higher voltage of 8V-22V considerable flow occurred in the channel. Fig 4 is a graph of measured fluid drop in the beaker against applied voltage. The fluid drop was steady at varying applied voltage from 2V-22V. Fig 5 is a graph of power consumed versus measured fluid drop. The power consumed was between 0.80W-165W . Fig 6 is the efficiency graph for the microchannel. Maximum efficiency was 32.96%.The microchannel efficiency dropped again due to the deformable nature of the hydrogel.

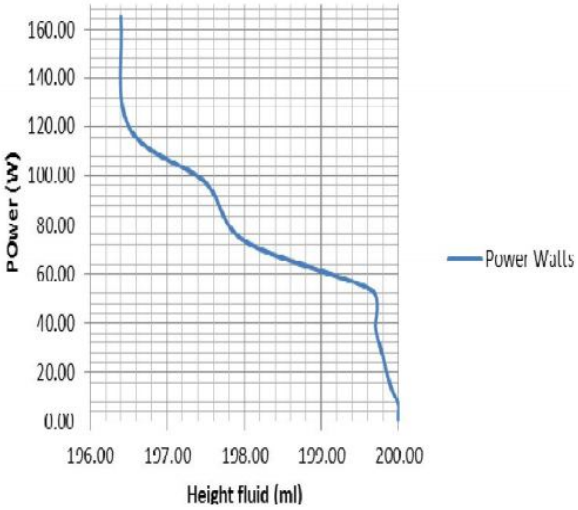


Fig. 2: Power Consumed against Height of Fluid drop in Hydrogel Microchannel % PVA/AA Hydrogel 800µm

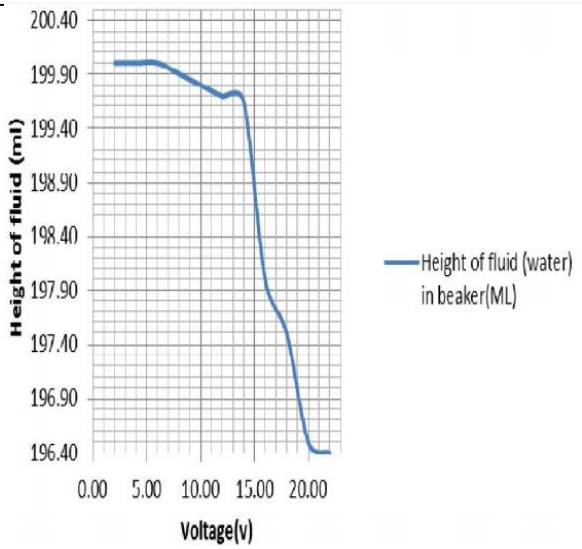


Fig. 3: Height of Fluid drop in Beaker against applied Voltage at 39:61 % PVA/AA Hydrogel 800µm at 39:61 Crosslink

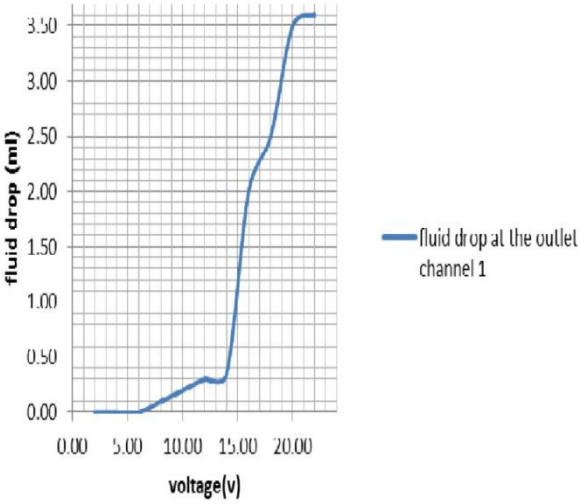


Fig. 4: Height of Fluid drop at Outlet against Voltage for Hydrogel Rise in Microchannel 800µm 39:61 % PVA/A Crosslink

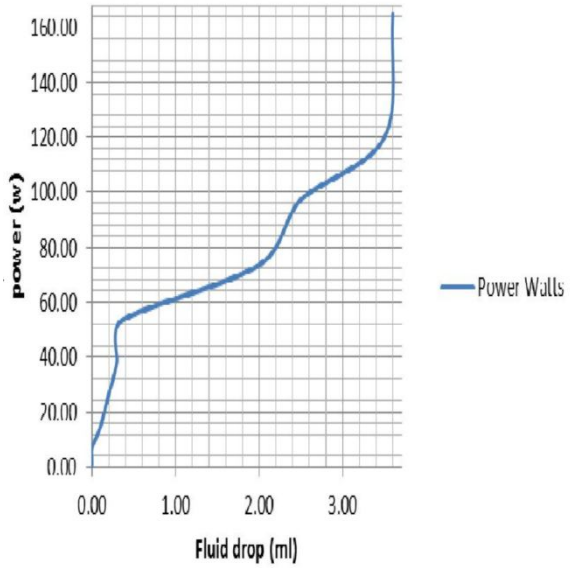


Fig. 5: Applied Power against Height of Fluid applied rise Hydrogel Microchannel at 800µm 39:61 % PVA/AA Crosslink

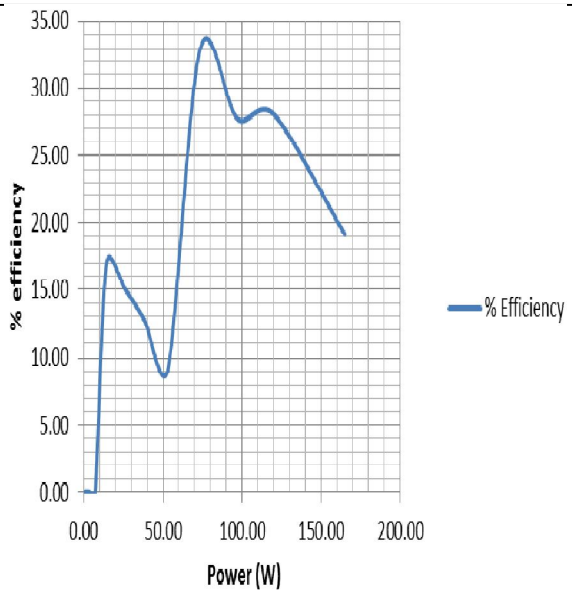


Fig. 6: Efficiency against Power consumed for Fluid Rise in Hydrogel Microchannel 800µm 39:61 % PVA/AA

Result and Discussion for Upward Flow Propulsion in Microchannel with Hydraulic of 1000µm

Microchannel with a crosslink ratio of 50:50% and a hydraulic diameter of 1000µm exhibited no traces of fluid flow when 2 V—6 V was applied. At higher voltage (8 V-22 V) there were drops in water level in the beaker. Fig 7 is a graph of fluid drop against applied voltages on the 1000µm hydraulic diameter microchannel. Fig 8 is height of the fluid inside the microchannel at varying applied voltage. The increase in height with applied voltage indicated that considerable flow occur in the channel. Fig 9 is a graph of efficiency against power consumed for hydrogel microchannel of 1000µm.The efficiency is higher when the applied voltage is low. The maximum power consumed was 165watts, not much different than the 800µm channel.

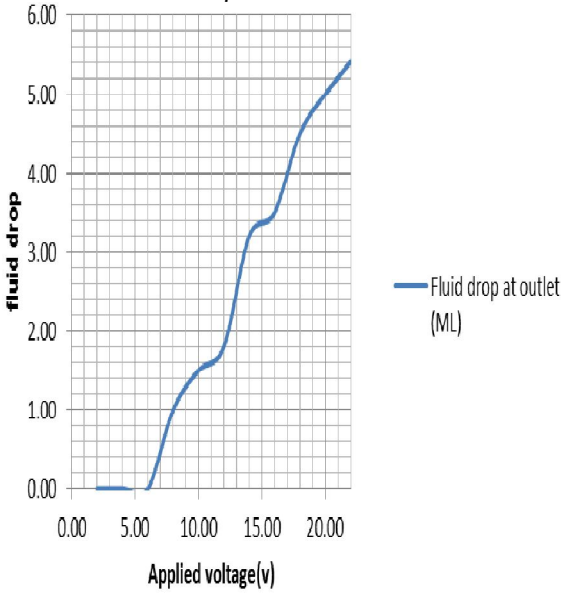


Fig. 7: Outlet Fluid discharge versus applied for Hydrogel Microchannel at Hydraulic diameter of 1000µm 50:50 % PVA/AA

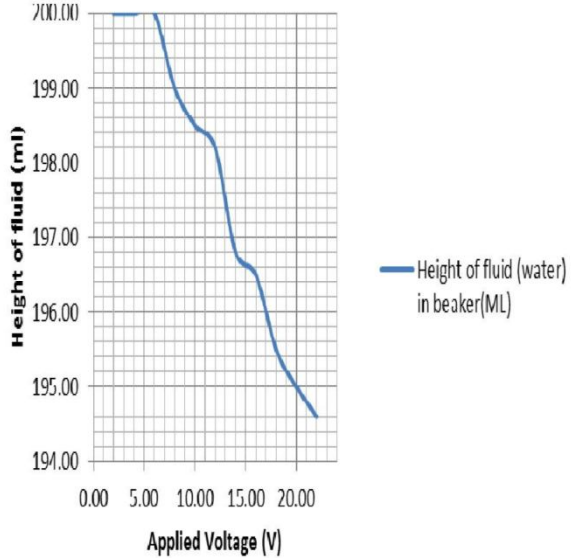


Fig. 8: height of Beaker Fluid Drop against against Voltage applied Voltage 50:50 PVA/AA Hydrogel Crosslink

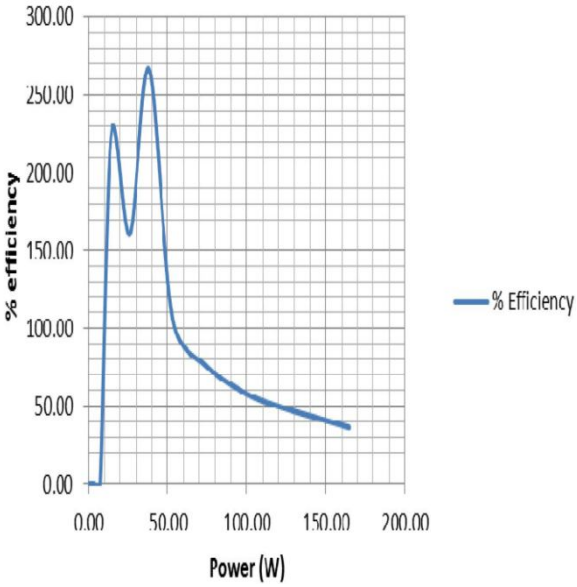


Fig. 9: Efficiency against power consumed for hydrogel Microchannel 1000µm At 50:50 PVA/AA Hydrogel Crosslink

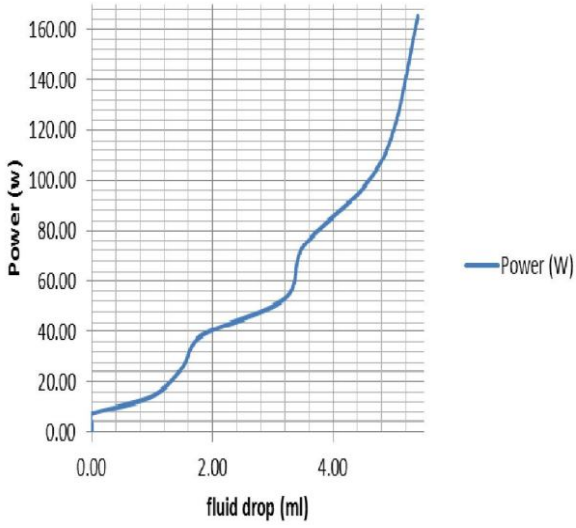


Fig. 10: Power against Fluid Rise in Hydrogel Microchannel 1000µm At 50:50 PVA/AA Hydrogel Crosslink

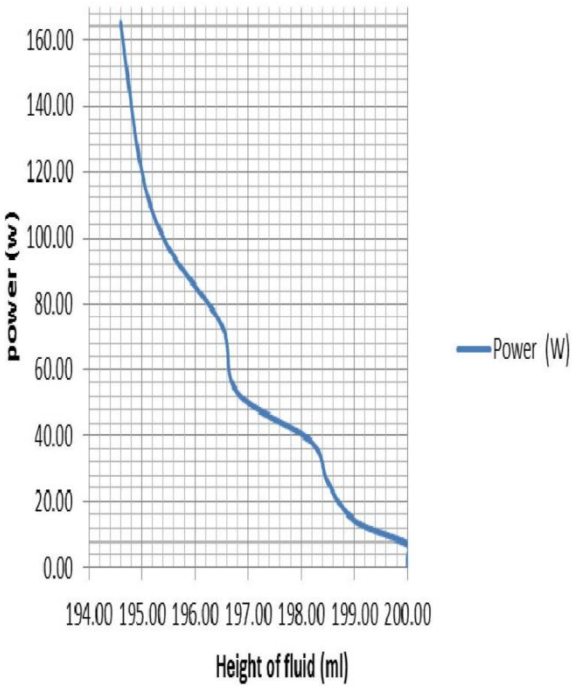


Fig. 11: Powers Consumed against height of fluid for hydrogel Microchannel 1000µm At 50:50 PVA/AA Hydrogel Crosslink

Result and Discussion for Electrically-Induced Upward Flow Propulsion in Microchannel with Hydraulic of 1200µm

Fig 12 is a graph of fluid drop against applied voltages on 1200µm hydraulic diameter microchannel. Figs. 13-16 were comparatively similar to the other two cases discussed. However the maximum power consumed at 176 W was higher, although the pumped height is greater than for the other two cases.

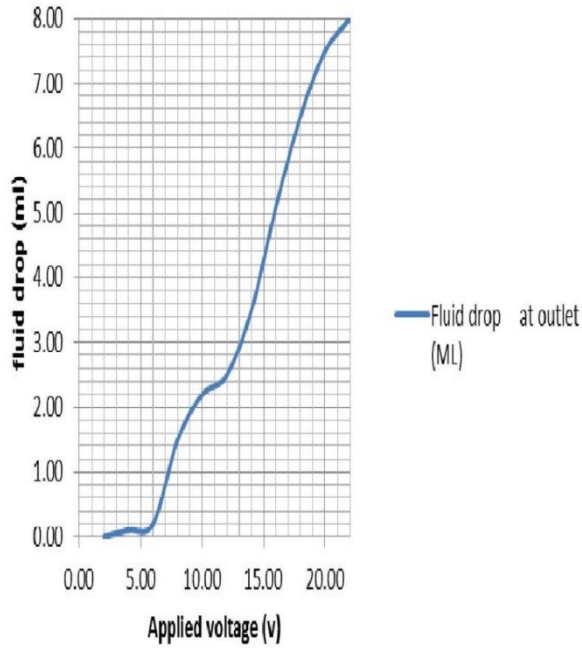


Fig. 12: Outlet Fluid discharge against applied voltage hydrogel Microchannel 1200µm

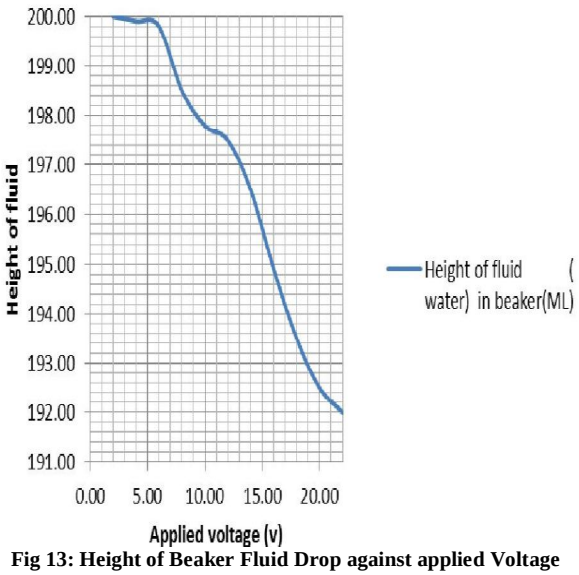


Fig 13: Height of Beaker Fluid Drop against applied Voltage for hydrogel Microchannel 1200µm

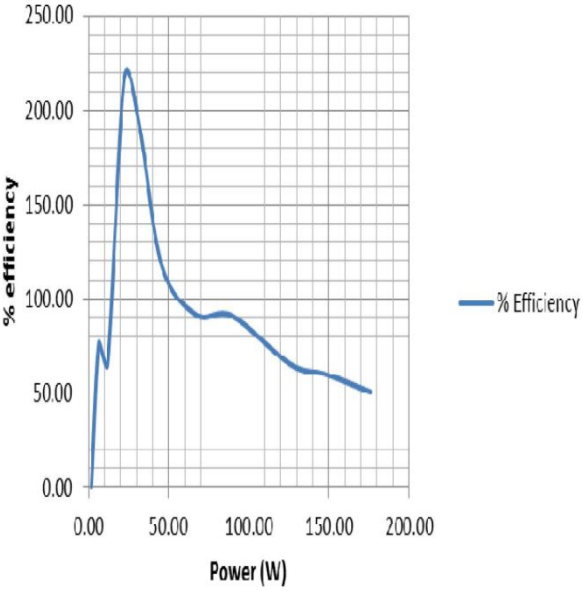


Fig. 14: Efficiency of Micro-pump against Power Consumed for hydrogel Microchannel 1200µm

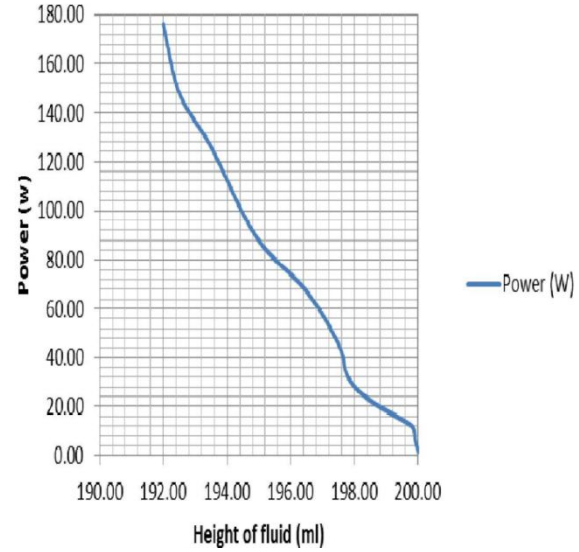


Fig. 15: Powers against height of Beaker Fluid drop at 60:40 PVA/AA Hydrogel

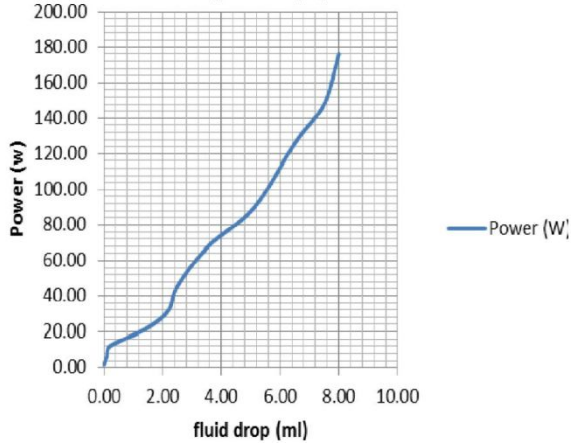


Fig.16: Power against Fluid rise for hydrogel Microchannel 1200µm

Result and Discussion for Electrically-Induced Upward Flow Propulsion in Microchannel with Hydraulic of 1400µm

Fig 17 is the graph of power against the height of fluid in the beaker, as power increases there was a drop in the height of fluid in the beaker. Fig 19 is a graph of fluid drop against applied voltages on Microchannel of 1400µm hydraulic diameter. In this graph at application of 2V no fluid drop at the outlet, on applying 4V-22V of voltage fluid flow occurred and at higher rate than the other cases. This showed that with increase in hydraulic diameter of a microchannel there will be increase in flow rate. Fig 20 is a plot of the height of the fluid against voltages for channel with hydraulic diameter 1400µm. At 4V there was little flow through the channel, but at higher voltage of between 6V-22V considerable flow occurs in the channel. Fig 21 is a graph of efficiency versus power consumed for hydrogel microchannel with hydraulic diameter of 1400µm.At consumption of between 0.0W to 10.2W efficiency increases and was between 0%-360%. On consumption of higher power between (12W-180W) the microchannel experiences drop in efficiency. The drop in efficiency is due to the hydrogel microchannel response to electrical stimuli which cause swelling and bending of the channel.

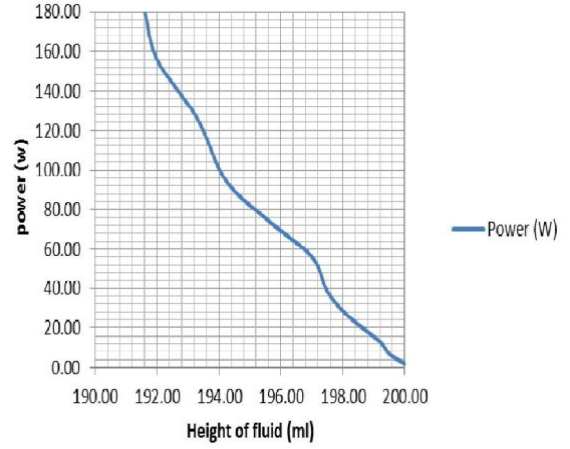


Fig. 17: Power against Outlet discharge hydrogel Microchannel 1400µm at 60:40 PVA/AA Crosslink

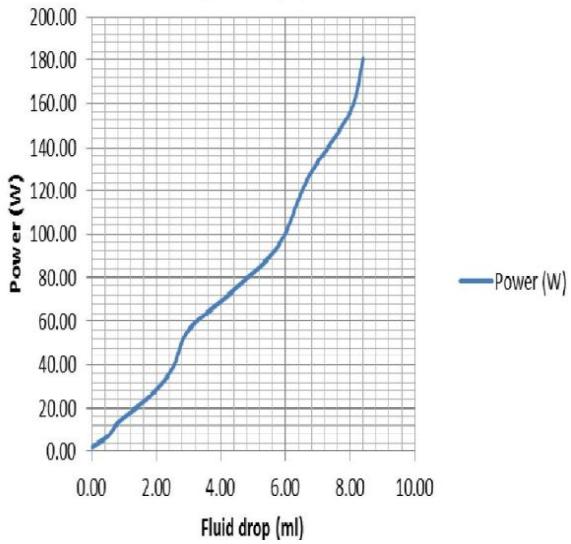


Fig. 18: Powers against Fluid rise in hydrogel Microchannel 1400µm 60:40 PVA/AA Crosslink

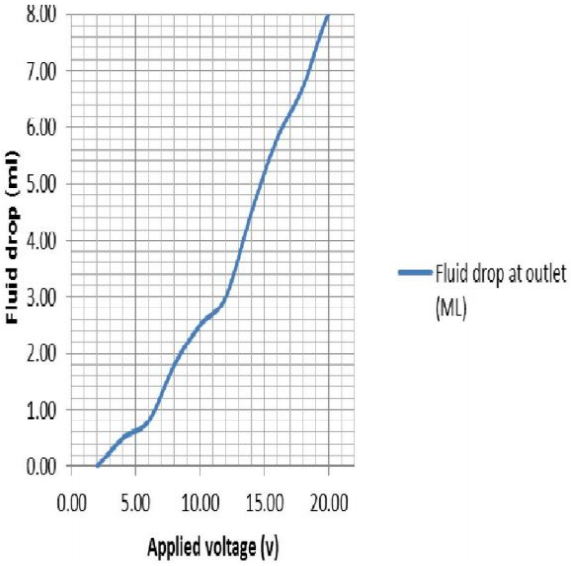


Fig. 19: Outlet Discharge against applied voltages for hydrogel Microchannel 1400µm At 60:40 PVA/AA Crosslink

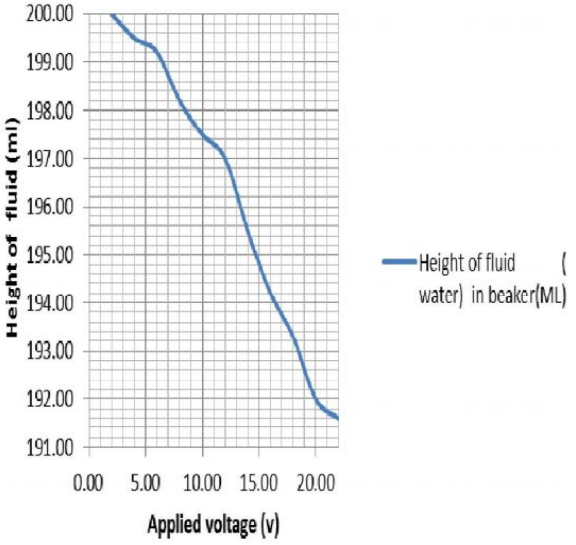


Fig. 20: Height of Beaker Fluid drop against applied voltage for hydrogel Microchannel 1400µm at 60:40 PVA/AA Crosslink

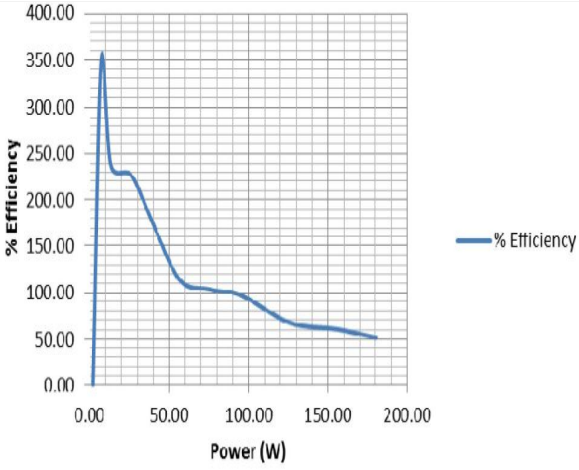


Fig. 21: Efficiency against Power consumed for hydrogel Microchannel 1400µm at 60:40 PVA/AA Crosslink

CONCLUSION

PVA/AA crosslink hydrogel have been seen in this study as a choice material for fabrication of microchannel of various hydraulic diameter and length. Though it was observed to have low electroresponsivity, but with the addition of biomolecules and otherwise putting of copper particles its response to electric stimuli has been tailored. It thus shows high response to electric field. The result from the experiment show that application of varying voltage triggered flow of fluid through microchannel of various sizes, which increases with increase in hydraulic diameter of PVA/AA hydrogel microchannel. The power dissipated for flows to occur in these microchannels increases with increase in hydraulic diameter. However lower voltage have higher efficiency but low lift. . The microchannel based on this study could thus as a micropump with likely saving in power.

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