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Fabrication of PDMS Microchannel using Stereolithography (SLA) 3D-Printer Mold

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ABSTRACT

Microfluidic systems have captured the attention of both the scientific and industrial communities, focus on applications in medicine and pharmaceuticals. Conventionally, the fabrication of microchannels within MEMS (Micro-Electro-Mechanical Systems) has heavily relied on the SU-8 mold. However, the cost of SU-8mold equipment, combine with the complicated and time-consuming fabrication process has trigged the research of the alternatives. This paper demonstrates a low-cost, simple, and easy fabrication of PDMS microchannel using a 3D-printer mold as the substitute for the conventional SU-8 mold. In this study, the process of fabricating PDMS microchannel using an SLA 3D-printer mold is highlighted. The fabrication starts with the combination of PDMS solution and the bonding agent and cured by heating process to form PDMS microchannel. The significance of pre-heated mold before pouring PDMS into the mold is highlight in this paper due to creation of bubbles in cured microchannel PDMS when using an unheated mold. Experimental findings point to the optimum temperature for curing the PDMS is at 65°C to get a good PDMS microchannel structure for bonding with the glass substrate. The practical utility of the PDMS microchannel is examined by varying the voltage from 1.2 V – 2 V for different concentrations of NaCl solution. The NaCl solution is successfully diffused from point A to point B for a length of 120 µm. Finally, the PDMS microchannel is successfully fabricated using an Stereolithography (SLA) 3D-printer mold and the functionality of the PDMS microchannel is validated for diffusing fluid through this system. This approach can be applied for various applications, e.g., a drug delivery system and a Lab-on-Chip system.

1. Introduction

Presently, microfluidic systems have gained the interest of the scientific and industrial community, particularly in the fields of medicine and pharmaceuticals. Microfluidic system can integrate with other system likes micropump and micro actuator to perform a mini laboratory analysis on a much smaller scale compared to recent methods, resulting in reduced sample consumption, cost, and equipment size as mentioned by several authors [1-4]. A typical microfluidic

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device is a set of microscale channels fabricated for managing small quantities of fluids to accurately execute both chemical and biological analyses written by several authors [5, 6]. Rapid DNA sequencing stated by Thaler *et al.,* [7] or a high level of precision point-of-care settings for disease diagnosis mention by Tsao *et al.,* [8] are examples of different applications where these devices can be applied written by I.S. Mohammad *et al.,* [9]. However, one of the crucial points in the development of a microfluidic device is choosing the appropriate apparatus for the fabrication mention by several authors in [10-12]. Apart from the other materials, polydimethylsiloxane (PDMS) polymer is one of the most commonly used materials in microfluidic devices reviews by a few authors [13-15]. This elastomeric material extends valuable properties, especially for biological applications, drug delivery, and DNA sequencing besides being an inexpensive polymer. PDMS-based microfluidic devices are typically fabricated by soft lithography, a high-precision technique that requires significant labour and capital investment, making it difficult to disseminate these devices outside of research laboratories. Moreover, soft lithography only allows the fabrication of 2D PDMS devices.

The microfluidic instrument has been refined by combining different parts so it can function as a fully automatic microsystem and prevent more contamination and human interference. In the last decade, SU-8 mold has been used to make microfluidic instruments. The SU-8 mold has been selected by many researchers for its excellent mechanical properties, water insolubility, biocompatibility, and chemical resistance after polymerization taken from de Almeida *et al.,*[16]. Furthermore, it allows for preparation with high aspect ratios, which is a basic need for the design of a new functional mechanical structure in MEMS. However, with all the excellent quality of SU-8 mold, it comes with a big cost behind it which will cause a huge effect on smaller industries. Additionally, the process to fabricate it is also complicated.

Therefore, to extend the potential of microfluidic devices to the next horizons, it is vital to advance new approaches that allow their fabrication within a shorter period, are cheaper, and with great accuracy. Currently, with all its excellent qualities, polymer 3D printing technology has been called the substitute for soft lithography in the fabrication of microfluidic devices and is becoming one of the leading technologies of this era as authors mention in [17, 18]. Interest in 3D printing has improved nowadays due to the effect of the diverseness and attractiveness of the technology's functions, which are considered some of the fundamental pillars of Industry 4.0 stated by Hedge *et al.,* [19]. 3D printing technology has been used in applications such as robotics, aerospace, bioelectronic, and medical applications among others as stated by Waheed *et al.,* [14]. This technology encompasses a range of processes and techniques that use digital blueprints to build up a component by applying materials layer by layer as stated by Chiado *et al.,* [12]. With this fabrication technique, true 3D, complex-shaped, and customised microfluidic devices can be produced in a single step within minutes or hours.

The purpose of this paper is to demonstrates a low-cost, simple, and easy fabrication of PDMS microchannel using a 3D-printer. This paper also emphasizes the importance of pre-heating the mold before pouring PDMS into it, as it effectively addresses the issue of bubble formation in cured microchannel PDMS when an unheated mold is utilized. The comparison between the fabrication of microchannel using SU-8 mold and the 3D printed mold are very different. The fabrication in 3D-printed mold is much simpler and the cost are lower. This paper shows the successful result of fabrication of PDMS microchannel using the 3D printed mold and a successful functionality test. This will replace expensive manual microfabrication methods and simplify the fabrication of complex lab-on-chip (LOC) devices relative to traditional fabrication systems such as soft lithography as mention by Frascella *et al.,* [20].This paper highlights a low-cost and easy fabrication method for fabricating a PDMS microchannel using a 3D-printer mold. Stereolithography (SLA) material was used due to this material having a high printing resolution with economical costs for materials and equipment taken from Zhang *et al.,* [21]. In this way, microfluidic chips could become more accessible to researchers and industrial users in various application areas, leading to accelerated innovation in the world of microfluidics.

2. Methodology

This paper focused focuses on an alternative method to fabricate a microfluidic device in using a rapid, ease easy and low-cost method instead of the conventional method which used uses the MEMS fabrication process. This new method will diminish a few steps likes such as the lithography process, spin coating, pre-bake, and post- bake etc to in developing a microfluidic mold. The usage of 3D- mold printer has been recently used in fabricating 3D microfluidic devices. However, this paper focuses on fabricate fabricating the mold using the 3D printer and the PDMS microfluidic device. The fabrication process is divided into two parts which is are to fabricate the 3D-mold printer of the microchannel and the PDMS fabrication for the microfluidic device development. Firstly, the schematic of the microfluidic molds was sketched with the mold size of 64mm x 24 mm. For microchannel has been set to 0.6 mm with microchannel a length is of 30.0 mm and while the size of the reservoir is 10 mm x 10 mm as depicted in Figure 1. The mold was fabricated using the 3D printer ANYCUBIC Photon M3 Max 3D printer with the specific setup measurement. Stereolithography (SLA) is used due to its capability to produce plastic parts with high resolution and precision, fine details and smooth surface finishing.

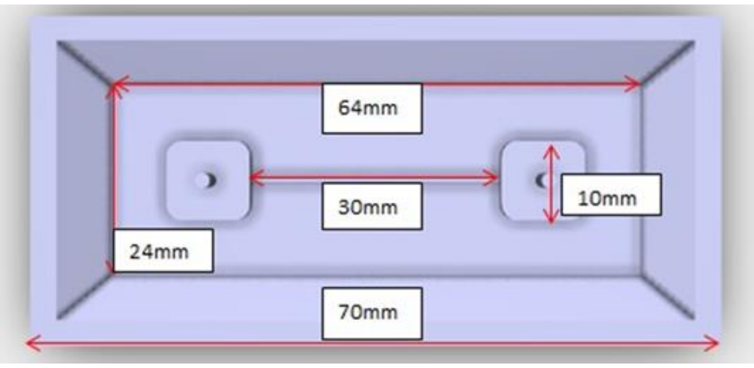


Fig. 1. The schematic of the microfluidic mold

The Tygon S3™ tubing with an inner diameter of 1/32″ was cut to 3 cm length and bonded with PDMS in the 3D mold as taken from previous studies by Norhafizah *et al.,* [22]. With a weight ratio of 10:1, the PDMS and the curing agent were prepared. The mixture of PDMS and the curing agent were stirred thoroughly to mix it well. The process of stirring the mixture produces bubbles in PDMS. After the oxidation process through the PDMS surface took place, the bubbles were removed by placing the solution in a vacuum chamber at 0.5 bar for 60 minutes. The result of stirred PDMS before and after the degassing process is shown in Figure 2.

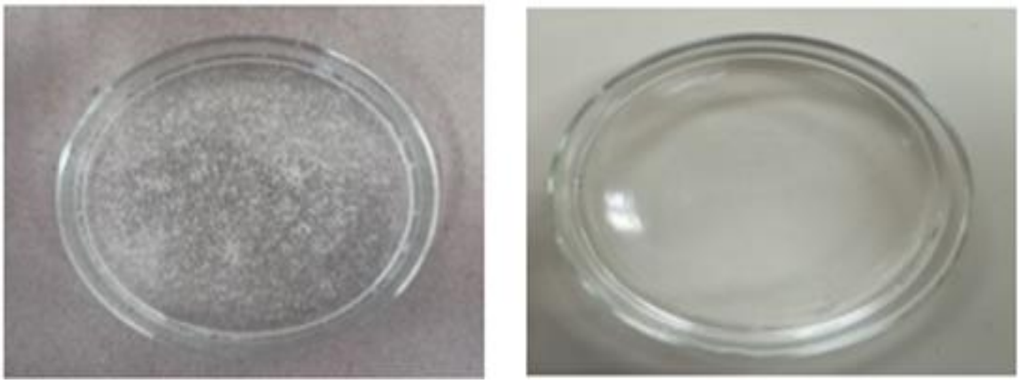

(a) (b)

Fig. 2. (a) PDMS solution (a) before degassing process (b) after degassing process

Before pouring the PDMS solution, the mold needs to be pre-heated for 30 minutes. The pre-heated procedure is the main contribution of this paper due to the bubble creation if this procedure is skipped. An effect of pre-heat is observed by varying the temperatures at 55 ^{o}C, 60 ^{o}C and 65 ^{o}C for 30 minutes. This step is performed to investigate the optimum pre-heat temperature for avoiding bubble creation during the hardening of PDMS. Furthermore, this study is also necessary to avoid any deforming structure of the mold. Then, the PDMS solution was poured into the microfluidic mold and cured in the oven for 60 minutes at 60 ^{o}C – 70 ^{o}C. Next, the PDMS will be peeled off from the mold using tweezers and directly bonded to the glass substrate. A corona discharge treatment is needed for the PDMS to ensure the glass has been bonded. Furthermore, this treatment is commonly used to improve the wettability, adhesion, and biocompatibility of a polymeric surface, without affecting the bulk properties as in previous studies by Wypych *et al.,* [23]. The fabrication schematic process of bonding and integration procedure is illustrated in Figure 3. In preparation for testing, NaCl was diluted in DI water. Next, the syringe pump was connected to the inlet and the beaker at the outlet. The DC power supply is connected to the copper wire which functions as the electrode in this microfluidic system. The voltage supply is varied from 1.2 V to 2 V to study the fluid flow in the microchannel. A microscope is placed on the top of the microchannel during the testing procedure to examine the fluid flow on the microchannel as shown in Figure 4. Then, this testing procedure is repeated for sodium chloride solution with a DC power supply ranging from 1.2 V to 2 V at various concentrations. The effect of potential difference with different concentrations of sodium chloride will be discussed at the end of the paper.

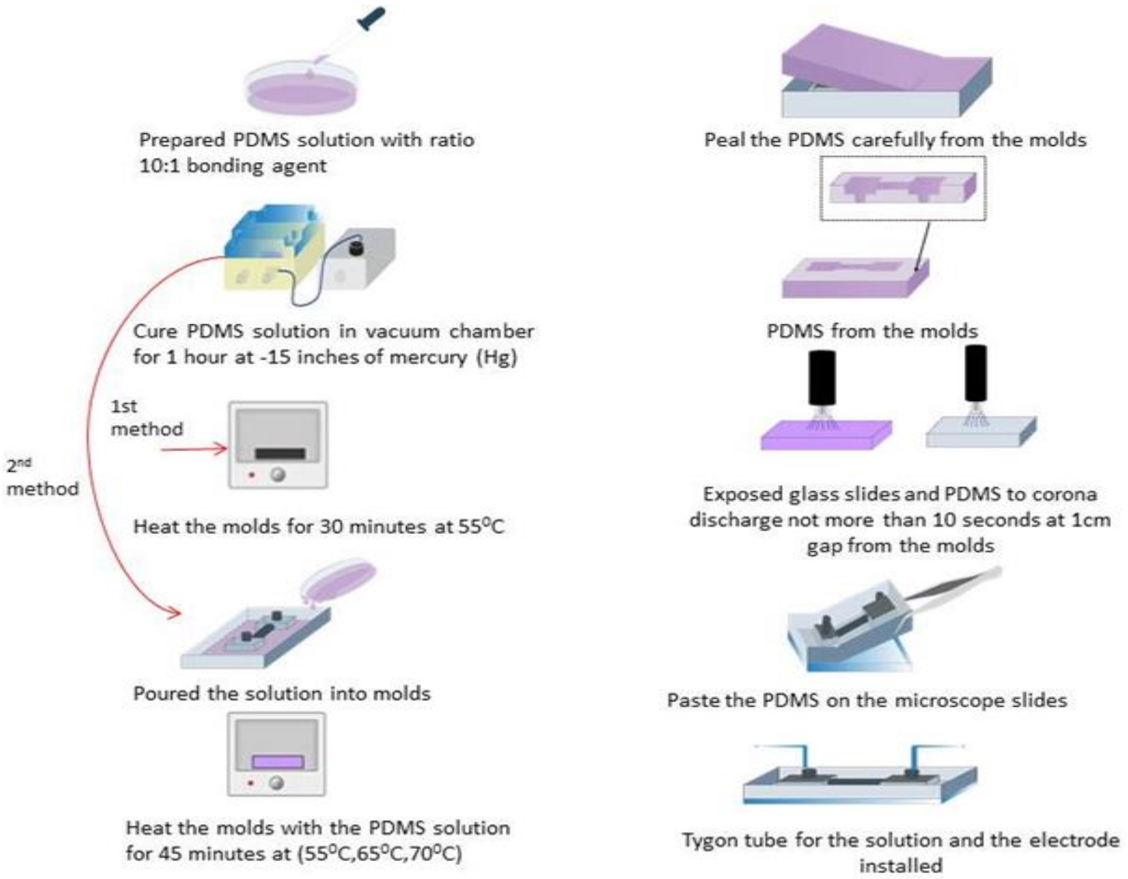


Fig. 3. Fabrication process for the PDMS microchannel

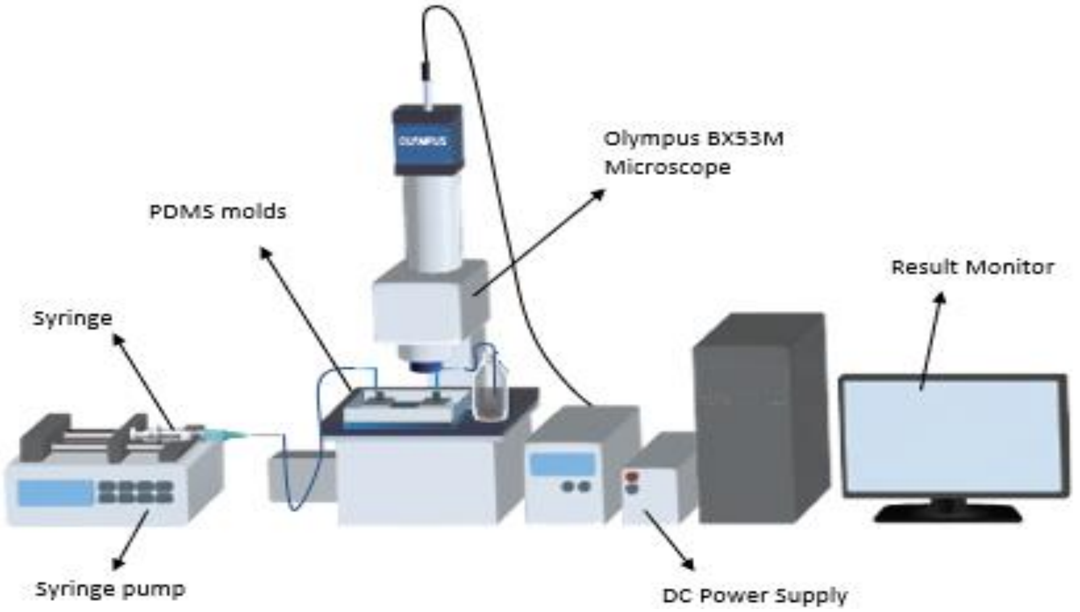


Fig. 4. Experiment setup to observe the fluid flow

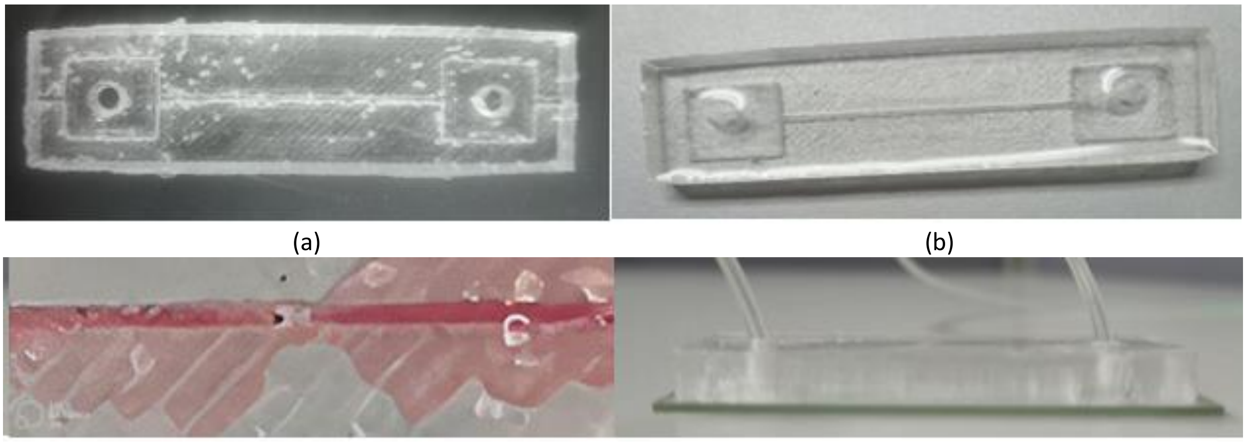
3. Results

3.1 Heated and Unheated Molds

This section discussed the performance of the heated and unheated molds by observing the cured PDMS microchannel produced using both types of molds.

3.1.1 The effect heated and unheated mold

From the results, the bubbles were formed on the PDMS microchannel when using the unheated mold even though the degassing process was done. The small bubbles were scattered in the cured PDMS structure as seen in Figure 5(a). However, no bubbles were observed for the cured PDMS microchannel sample using the heated mold. The result was consistent for all samples with at 55 °C, 60 °C and 65 °C heating temperatures. The bubbles will eventually will produce uneven surfaces on and inside the microchannel which may lead to unwanted leaking problems during the testing procedure as in Figure 5(c). Hence, this range of temperature was acceptable to prevent bubbles creation during the curing process of the PDMS microchannel. Also, it was found that the optimum temperature for curing the PDMS was 65 °C to ensure its surface was not too dry for a better bonding process. Figure 5(d) shows the final PDMS microchannel after bonding on a glass substrate.

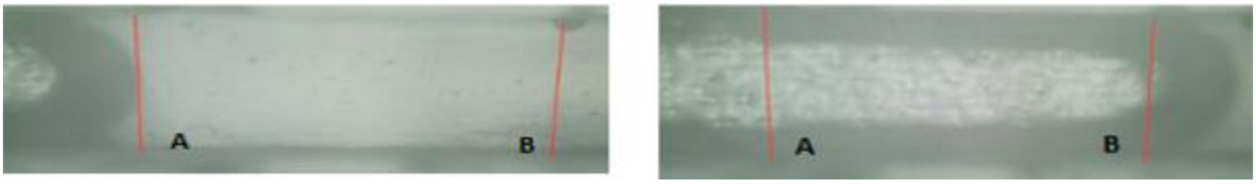

(a) (b)

(c) (d)

Fig. 5. (a) Unheated 3D mold (b) preheated 3D mold (c) leaking in microchannel (d) bonded PDMS microchannel with a glass substrate

3.2 The Functionality of the Microchannel

In this section, the functionality of the microchannel with the size of 0.6 mm has been tested using different concentrations of sodium chloride with the various supplied voltages supplied ranging from 1.2 V to 2 V. The effects of NaCl concentration and different supplied voltages supplied were observed in terms of the fluid flow and bubbles creation in the fluid. The flow characteristics were observed under an optical microscope by measuring the time taken for the NaCl to travels from point A to point B with the a distance of 120 µm. The migrations of the NaCl solution inside the microchannel under the electric field influence are is shown in Figure 6.



(a) (b)

Fig. 6. NaCl travels from A to B with a distance of 120 µm (a) starting point (b) fluid reaches the B point

According to Figure 7, the time taken for the NaCl to flow from point A to point B increased linearly as the voltage was increased for all concentrations. Further observation at the inlet reservoir where the electrode was placed found that bubbles were produced at all voltages supplied. As the voltage potential is increased, the number and size of the bubbles also increased. This event will affect the fluid characteristic inside the microchannel and may cause unnecessary effects on the fluid velocity as per mentioned in by a few authors *et al.,* [24, 25]. Here, the fluid flow from point A to point B was interrupted by the bubbles created inside the reservoir.

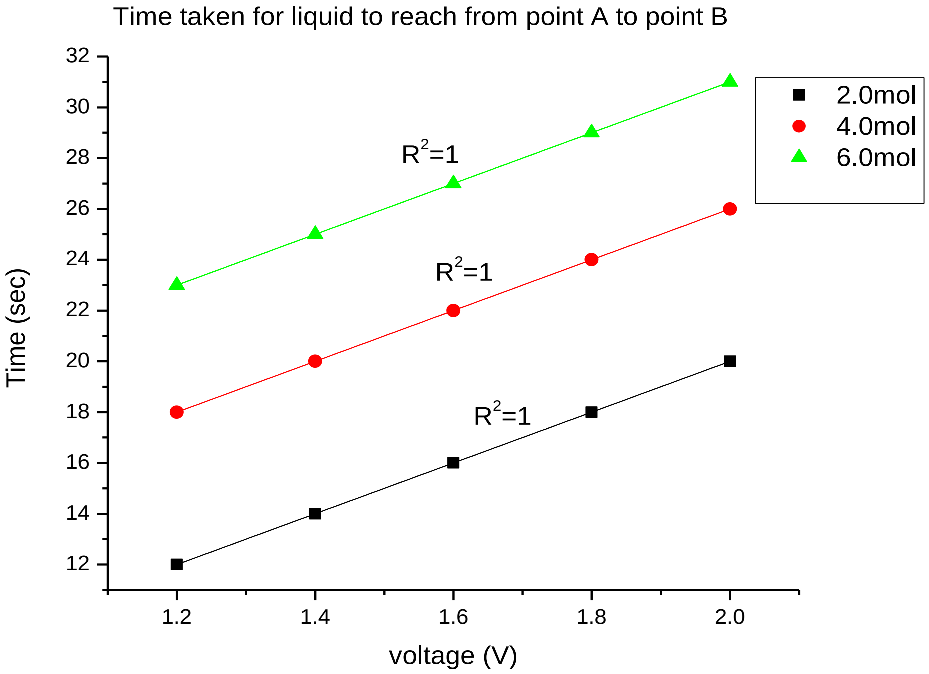


Fig. 7. The time taken for NaCl to reach point A from point B

Next, the speed of the fluid can be determined by considering the time taken for the fluid to reach the 120 µm length. The speed of the fluid was inversely proportional to the voltage change. The fluid velocity became slower with the increasing voltage potential for each mol as depicted in Figure 8. This statement is agreed in [25] which stated that increasing the applied voltage decreases the fluid flow. In addition, it was found that with the increase of NaCl molarity, the fluid flow also decreases by 15 % – 30 % for each concentration.

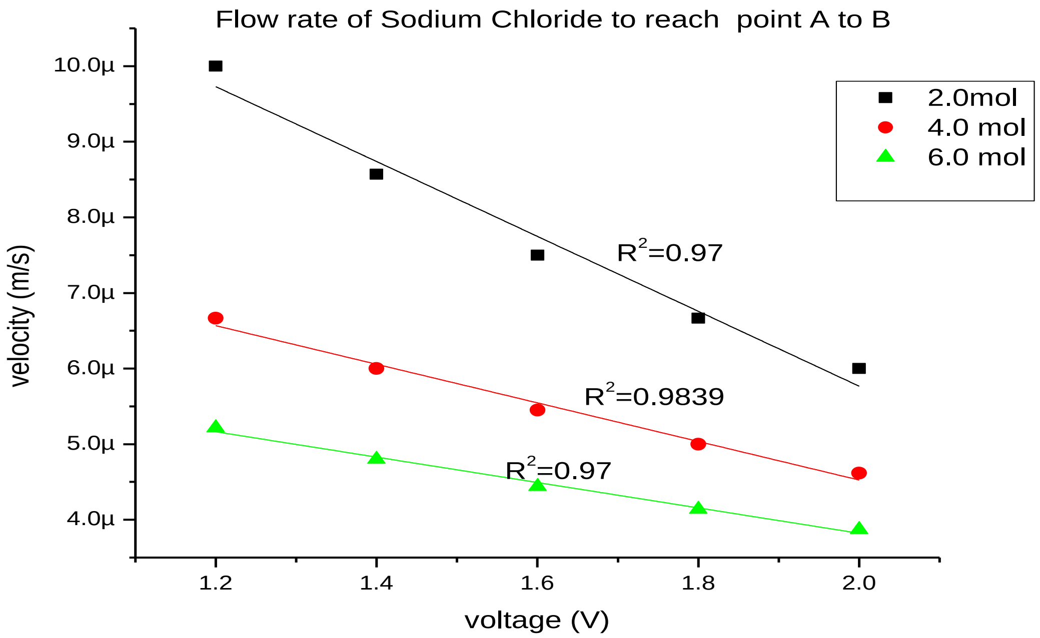


Fig. 8. Flow rate of NaCl to reach point A from point B

4. Conclusions

As conclusion, a PDMS microchannel utilising 3D printing technology for mold fabrication was has been successfully fabricated. The process was obviously cheaper and simpler than the SU-8 mold fabrication process. The microchannel with a satisfactory surface condition was successfully fabricated using an SLA mold. The heated mold produced a microchannel with finer and smoother surface compared to the fabricated microchannel using an unheated mold. The temperature of 65°C was the optimum temperature for curing the PDMS to get a good PDMS microchannel structure for bonding with the glass substrate. The functionality of the microchannel to diffuse the fluid was observed by using NaCl solution. The concentration and voltage potential were varied to observe the flow characteristics inside the microchannel. The speed of the NaCl flow was calculated by the measureding the time taken for the fluid to flow from point A to B with the a length of 120 µm. The highest fluid speed was found at 2.0 mol NaCl. With the increasing of the NaCl molarity, it resulted in the decreasing of the fluid flow by 15 % – 30 % for all concentrations. The most importantly, this study successfully demonstrated a fully functioning PDMS microchannel fabricated using a 3D printer mold.

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