CHAPTER 4

FABRICATION OF MICROFLUIDIC PAPER-BASED ANALYTICAL DEVICE (μPAD)

4.1 Experimental

4.1.1 Materials

Materials used to fabricate μPADs in this study were commercially sourced paraffin wax and Whatman cellulose-based grade 1 chromatography paper sourced from Sigma Aldrich, USA. Flow rate assessment of the fabricated μPADs performed using distilled water obtained from research laboratory.

4.1.2 Fabrication of μPADs

The paper used to fabricate the μPADs were patterned with intended design (inlet, outlet, channel, and barrier) with a stencil. The hydrophilic channel of the μPADs were formed as the paper was treated with paraffin wax to form the hydrophobic barrier. Upon finishing the paraffin wax treatment onto paper, the paper was dried for 5 minutes. The finished fabricated μPADs is shown in Figure 4.1.

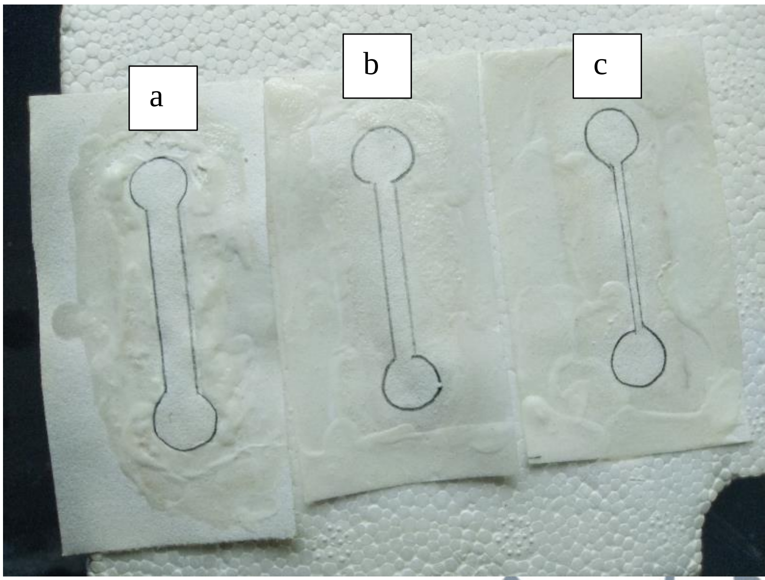

Figure 4.1: Fabricated μPADs with different channel widths ((a) 5.0 mm, (b) 3.0 mm, (c) 1.0 mm) after wax treatment and drying.

4.1.3 Flow rate assessment of μPADs

μPADs fabricated in this study were subjected to the volumetric flow rate evaluation. In-house prepared distilled was used to measure the flow through the channel of the μPAD. The volumetric flowrates were calculated using classical Lucas-Washburn equation, stated in Equation 6.

$$\dot{v} = \sqrt{\frac{\gamma r \cos\theta\, t}{2\mu}} \qquad \text{Eq. 6}$$

where; $\dot{v}$ = volumetric flowrate

γ = pore radius

θ = contact angle

t = time for liquid to travel from inlet to outlet

μ = dynamic viscosity

The variables investigated in this study were the width of the channel and the volume of liquid used in the inlet region. In order to study the effect of the width of the channel on the volumetric flowrate, the fabricated μPADs with channel widths of 1.0, 3.0 and 5.0 mm were used. 10 μl of distilled water was used to observe the flow of fluid along the channel. On the other hand, to study the influence of the volume of liquid used, only fabricated μPADs with channel width of 5.0 mm were used for testing. However, the volume of distilled water was varied at 10, 20, 30, 40 and 50 μl. The flow of distilled water was observed from the initial wetting of the inlet region to overall wetting of the outlet region, and the time taken for the flow to be fully wet the outlet region was taken and recorded.

4.2 Results and discussions

4.2.1 Flowrate from differing volumes of analyte

Differing the volumes of analyte also affected the flowrate as higher fluid volume increases volumetric flowrate. Studying the effect of differing volumes of analytes can determine the minimum sample volume with highest flowrate to ensure rapid analysis. The result of the study is depicted in Figure 4.2.

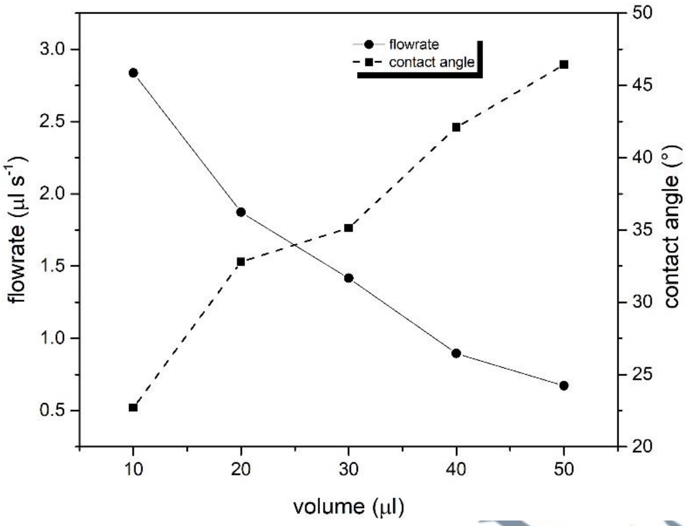

Figure 4.2: Effect of varying volumes of liquid onto the flowrate on μPAD in relation to the contact angle of liquid

Figure 4.2 shows the effect of varying the volume of liquid onto the flowrate on μPAD in relation to the contact angle of the liquid on the input region. From the figure, increasing volume of liquid lowered the flowrate of the liquid on μPAD. Using 10 μl of water yielded flowrate of 2.8361 μl s^{-1}, while using 50 μl of water yielded flowrate of 0.6713 μl s^{-1}. The changes of flowrate were explained by the changes of contact angle of fluid on the input region. It showed that using higher volume of liquids reduced the wettability of the input region, which portrayed by the increasing contact angle, θ of liquid upon introduced onto the input region. Nguyen and Wereley (2002) and Song et al. (2018) had summarized that contact angle of the fluid in the input region dictated the wettability of the fluid into the cellulose fibres of μPAD. Zero contact angle ($\theta = 0°$) indicated complete wettability of the input region. Thus, increasing the contact angle reduced the wettability of the input region. Due to reduced wettability, liquid dropped onto the input region spread through the channel at lower rate.

4.2.2 Flowrate from differing channel width

In the µPAD architectural design aspect, channel width can affect the flowrate of the fluid through the channel. Increasing channel width can both decrease and increase the flowrate as the channel width influenced the flowrate of the fluid. The statement is supported by Figure 4.3, resulting from the study.

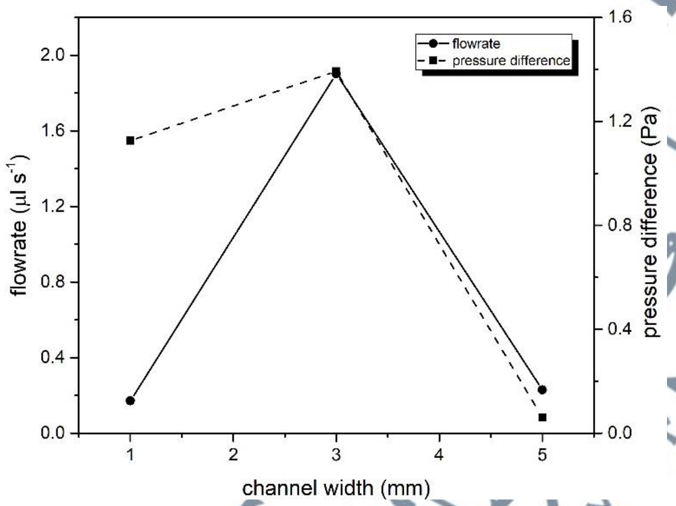

Figure 4.3: Effect of channel width on flowrate of liquid on µPAD in relation to the pressure difference between input and output region

Figure 4.3 shows the effect of channel width on the flowrate of liquid on µPAD. It was shown that the flowrate peaked at 1.9014 µl s^{-1} from 0.1707 µl s^{-1} when 100 µl of water used to measure its flowrate through µPAD with 3.0 mm channel width, then plummeted to 0.2298 µl s^{-1} after used on µPAD with 5.0 mm channel width. Fluctuations of the flowrate were caused by narrow channel (width = 1.0 mm) constricted the flow of fluid, thus resulting low flowrate of fluid through the channel. However, using µPAD with wide channel (width = 5.0 mm) also caused the flowrate to drop greatly. Referring to Hagen-Poiseuille equation, stated in Equation 7, cross sectional area of the channel was one of the factors influencing the flowrate and velocity of the fluid flowing through the channel (Ostadfar, 2016). Other parameters namely length of the channel and viscosity of liquid used fixed to be constant as both parameters can affect the flowrate greatly.

$$\dot{v} = \frac{\Delta P R^2}{4\mu L} \qquad \text{Eq. 7}$$

where;

ΔP = pressure change
R = channel radius
μ = dynamic viscosity
L = path length

The previous study showed flowrate of the liquid was influenced greatly from the channel width of the μPAD as shown by Lucas-Washburn equation (Equation 6). However, the study only covered the effect of the channel width on the flowrate of the fluid without the influence of the pressure differences between the input and output region as Lucas-Washburn equation did not factor in pressure differences as one of the factors in the equation.

4.3 Conclusion

From the study conducted, the flowrate of the fluid was influenced by both variables; volume of fluid used and the channel width. As a result, the lowest volume of fluid used on μPAD was 10 μl that gave out flowrate of 2.8361 μl s^{-1}, meanwhile the highest flowrate of fluid was 1.9014 μl s^{-1} when using channel width of 3.0 mm. The flowrate of the fluid shown to be decreased as increasing the volume of the fluid caused the wetting of the μPAD to be decreased. The flowrate of the fluid also shown to be fluctuated as varying channel widths was used in the study, due to the fluctuations of pressure changes.