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Enhancing the Flow in Microchannel using Natural Polymeric Additives

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Abstract

This present study aims to study the feasibility of three natural polymeric drag reducing additives in enhancing the flow in microchannel. Five mucilage solution concentration (100 to 500 ppm) was prepared by adding deionized water which acted as transported liquid after extracting from okra, aloe vera and hibiscus leaves. The additives were then tested in custom made microchannel simulating human heart blood vessels. The flow performance of different concentration of additives was evaluated by recording the flow rate across the microchannel corresponding to the operating pressure (50 to 500 mbar). Increasing of the additives concentration increases the %FI indicating that drag reduction occurred. However, continuous increasing of the concentration has negative effect on drag reduction where this limit is known as critical concentration. The maximum drag reduction up to 63.48% is achieved using 300 ppm of hibiscus mucilage. This work introduces an approach for flow enhancement in semi-clogged blood streams using natural polymers that could contribute as an alternative treatment for cardiovascular diseases.

Keywords: Drag Reduction, Drag Reducing Additives, Microchannel, Natural Polymers, Semi-Clogged Blood Vessels

1. Introduction

Numerous researchers start to introducing and investigating a different type of drag reducing additives (DRA) such as long chain polymers and surfactants to enhance the liquid flow in pipes and conduits after pioneer work from[1] in the 1940s. These additives have massive impacts in many industrial[2,3] and even medical[4] applications due to their properties that can reduce the drag significantly even used in a minute amount, usually in parts per million (ppm).

Polymers are more favorably by industries due to its low cost and availability in the market. However, most of the investigated polymeric Drag Reducing Additives (DRA) are synthetic polymers. These synthetic polymers are mostly non-biodegradable and consider as nonenvironmental-friendly products. Thereby, researchers started to investigate natural polymers as DRA in an attempt to replace the existing synthetic polymers.

In medical applications, natural polymers are used to enhance the flow of blood by reducing the vascular resistance. Drag reduction (DR) can also inhibit the growth of tumor cells due to the enhancement of blood flow by depriving extra supply of nutrients needed by the tumor cells. From the work of [5], polymers extracted from Aloe vera showed a better DR performance where artificial DRA did not show any. These results agreed with the work done by [6,7]. However, there were still limited studies on the feasibility of other natural polymeric additives which also have high DR performance besides Aloe vera in enhancing blood flow.

Recently, there are incredible enthusiasm on microfluidics technology to be applicable as an economical and reliable method for testing different theoretical phenomena related to engineering fields and medical fields. In experimental work such as drag reduction[8,9], the microchannel is useful in an attempt to replace the conventional method by using pipes. Microfluidic technology only manipulates the small volume of fluids thus reduces the wastage of chemical or reagents that prompt to environmental problems.

Therefore, in this present work, three different natural polymers as DRA namely okra, Aloe vera and hibiscus were extracted and studied in micro channels

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having the real size of human heart blood streams with a different clogging part in an attempt to simulate the flow in blood vessels. Open-loop microfluidic setup was utilized to carry out this experimental work. Note that the natural polymers are not intended to be used in human bloodstreams. The purpose of this investigation is to prove the feasibility of polymers with similar physical properties as DRA in enhancing the blood flow in semi-clogged blood vessels.

2. Materials and Methods

2.1 Material

Natural polymers were extracted from okra, Aloe vera, and hibiscus where these plants were purchased from local market. The plants were soaked in 1 liters of ultra-pure water separately for 5 hours under room condition and kept in the freezer (4 °C) overnight. The extraction process was completed when the plants produced mucilage and turned the liquid into a viscous liquid. The mucilage was then filtered to prevent any suspended solids from getting through. The filtered mucilage was evaporated at 40 °C and 90 rpm using rotary evaporator (model: IKA HB 10). The mucilage was ready for dilution to obtain the required concentration.

2.2 Experimental Procedure

An experimental apparatus was set up as shown in Figure 1 for obtaining drag reduction data at a wide range of all three mucilage concentrations.

Five different concentration of each mucilage extraction solution were prepared ranging from 100 ppm to 500 ppm. Mucilage was weighed accordingly and added to transported liquid, in this case, was deionized water, which will then being stirred manually. All the experiments were conducted in an open loop microfluidic system, experimenting on the effect of concentration of extracted mucilage on DR. The procedure began by testing all the five concentrations (100 – 500 ppm) of the natural polymeric additives; the operation started when the solution delivered across the tube length. Elveflow Smart Interface was used to execute commands to pressure and vacuum controller to manipulate the required pressure to push the solution out from the reservoir. By varying the pressure, flow rate across the tube length readings measured to the pressure were recorded. This method was repeated for each mucilage's concentrations to check its effect on the DR operation. The percentage of flow rate increment (%FI) was given as:

$$\%FI = \frac{F_a - F_b}{F_a} \times 100 \quad (1)$$

where

F_b = Flow rate before the addition of DRA (μL/min)

F_a = Flow rate after the addition of DRA (μL/min)

3. Results and Discussion

Figure 2 to Figure 3 shows demonstrated the %FI for all three extracted mucilage at various concentration for different operating pressure using two different microchannels, named Model 1 and Model 2 which have a different clogging area. The flow in the microchannel is always laminar. However, turbulent flow is expected to occur when flow through the narrowed area[10]. Averagely, in most of the cases, the trend of the %FI increases with the increases of the concentration where the maximum %FI achieved by utilizing ahigher concentration of mucilage for all the cases. Higher %FI indicated that DR happened where the flow rate of the liquid increased under the same operating pressure.

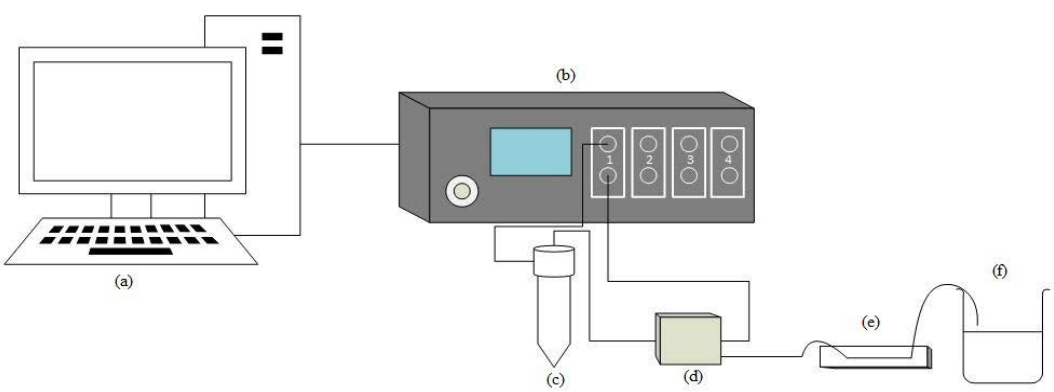

Figure 1. Schematic diagram of experimental setup consisted of (a) computer (b) pressure and vacuum controller (c) reservoir containing solution (d) flow sensor (e) custom made microchannel (f) beaker as storage tank.

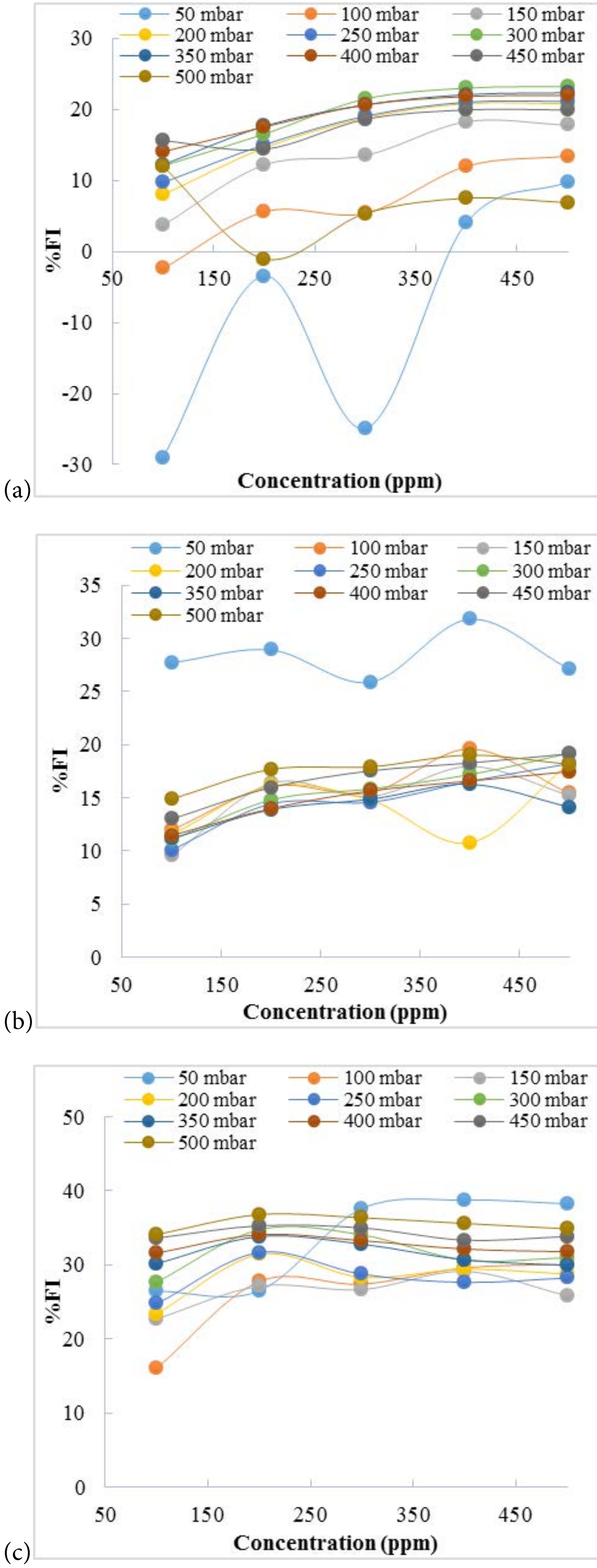

Figure 2. Variation of %FI at various (a) okra (b) *Aloe vera* and (c) hibiscus mucilage concentration for different operating pressure using Model 1.

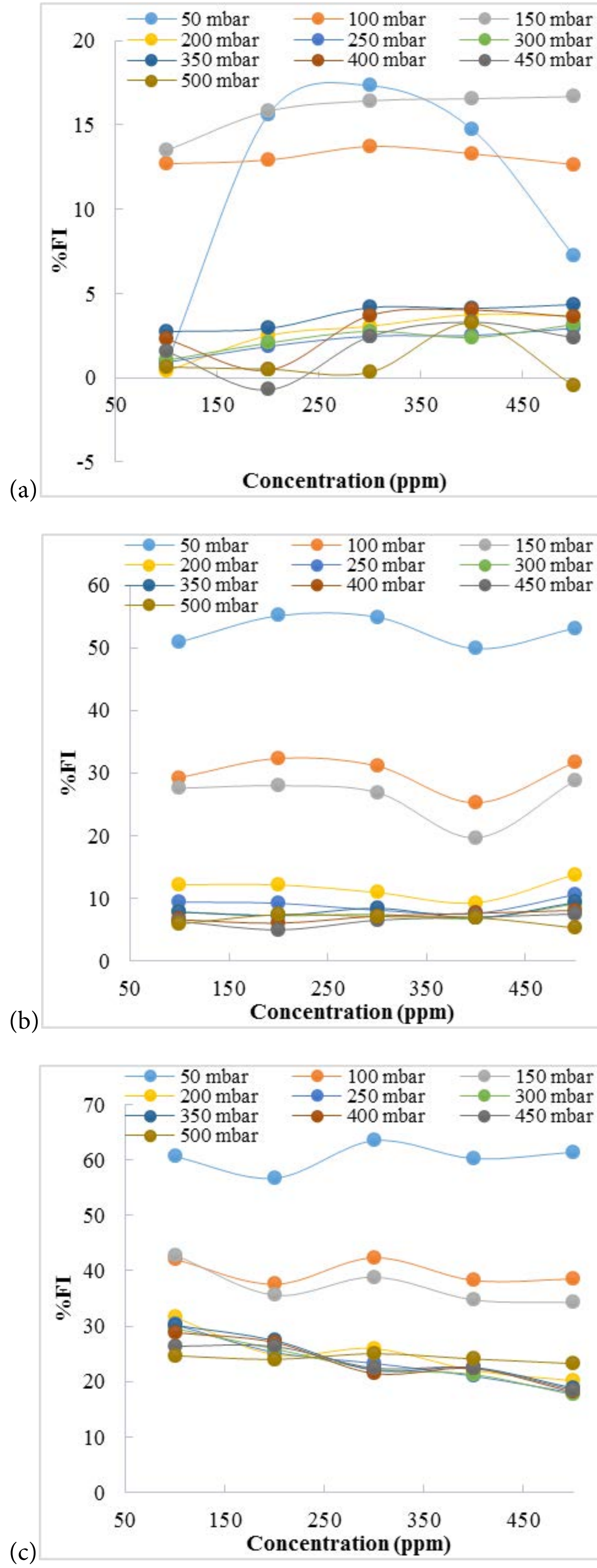

Figure 3. Variation of %FI at various (a) okra (b) *Aloe vera* and (c) hibiscus mucilage concentration for different operating pressure using Model 2.

When using okra mucilage as DRA in Model 1 shown in Figure 2a, increasing the concentration of the mucilage, the %FI increases significantly except for the operating pressure at 500 mbar. In this case, a higher concentration of the polymer indicates more polymer molecules involved in the DR operation[11] thus provides a bigger platform for the polymer to act as DRA.The maximum %FI was achieved up to 23.21% at operating pressure of 300 mbar when manipulating 500 ppm okra mucilage in this case.

As demonstrated shown in Figure 2b and 2c, the trend of %FI was unusually quite consistent throughout the increasing of the mucilage concentration. The pattern indicated that by increasing the concentration for both of the mucilage did not have much effect on DR performance. The difference of %FI did not exceed 20% and 10% for Aloe vera and hibiscus, respectively. However, higher %FI was achieved at higher mucilage concentration for all the cases. This phenomenon can be explained by that more polymers particles are involve in the DR operation at higher concentration of mucilage hence increases the liquid flow. For the case of Aloe vera, the maximum %FI was 31.82% achieved by using 400 ppm of Aloe vera mucilage at the operating pressure of 50 mbar. As for hibiscus, the maximum %FI was 38.75% performed by 400 ppm of hibiscus mucilage at 50 mbar.

Figure 3 displayed the %FI for all three extracted mucilage at various concentration for different operating pressure using Model 2. From Figure 3a, %FI was fluctuating with the increase of additive concentration. However, the average %FI increased with the increased of the mucilage concentration except for 100 and 500 mbar. This results indicated that higher okra mucilage concentration has better DR performance. The maximum %FI was 17.33% achieved by 300 ppm of okra mucilage at 50 mbar.

As illustrated in Figure 3b, continuous increasing the aloe vera concentration was observed not to have a significant effect on DR due to the insignificant increasing in %FI for the investigated concentration range. However, the average of the %FI increased slightly with the increased of the aloe vera mucilage concentration. In this case, %FI was expected to increase with the increasing of the mucilage concentration until it reached its critical concentration where further increasing will cause anadverse effect in DR. 200 ppm of aloe vera mucilage achieved the maximum %FI with 55.16% at the operating pressure of 50 mbar.

The result was contradicted with other cases when using hibiscus as DRA as shown in Figure 3c. Averagely, ahigher concentration of hibiscus mucilage had an adverse effect on DR except for operating pressure of 50 mbar. It was suspected that the optimum concentration of hibiscus, in this case, is 100 ppm where continuous increasing the concentration did not have the linear effect on %FI. The maximum %FI of 63.48% was utilizing 300 ppm hibiscus mucilage at the operating pressure of 50 mbar.

4. Conclusion

The effect of concentration of three different natural polymeric additives extracted from different sources namely, okra, *Aloe vera* and hibiscus were investigated using microfluidics technique. From the results, increasing of the concentration of the additives increases the %FI and thus increases the DR performance. However, there would be a limit, known as critical concentration, where continuous increasing of the mucilage concentration has negative effect on DR. The maximum %FI up to 63.48% was achieved when utilizing 300 ppm of hibiscus mucilage. The experimental results proved that these natural polymeric additives could be employed as DRA in enhancing the liquid flow. It is believed that natural polymers should be investigated in future to prove the DR effect in medical applications and to progress toward the introduction of a commercially feasible natural polymeric additives that can be used as an alternative treatment for cardiovascular diseases.

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