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Fabrication of 2D Membrane Castellated and Straight Electrode for Dielectrophoresis

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ABSTRACT

This paper is presenting two fabrication process of electrodes for the used in artificial kidney. The electrodes were made to compare which will represent the best results. Both electrodes undergoes same fabrications process which represent the novelty in this research. Membranes were fabricated in between the electrodes. Both electrodes were deposited with aluminium. Later both electrodes were tested experimentally to find out the result of particles on which electrode performs better. The experiment was taken for 3 minutes on each frequencies. Frequencies were taken during the positive DEP only which are between 100kHz until 3 MHz. The results shown that castellated electrodes able to cleared the particles much faster than straight electrodes. The faster particles cleared the pathways, which resulting particles moving towards the electrodes, this shows higher electric fields is produced. Higher electric fields shows that less voltage needed. Higher voltage has also been avoided in this research in order to avoid the change of biological nature of cells.

Keywords: DEP, RBC, Castellated Electrode, Straight Electrode.

1. INTRODUCTION

In the last few years, the number of patients with kidney failures in Malaysia had gone up to three million [1]. Based on the article by [1], number of dialysis patients are 40,000 and 20,000 patients are waiting for kidney donations. This is a serious matter due to the unhealthy lifestyle of Malaysians such as eating fast food, unbalanced food, and junk food. Not to mention, kidney is a precious organ that needs to be protected; it is a toxin remover which removes unwanted waste such as urine, extra potassium, extra sodium and etc. from the blood [2] to prevent damage to the body [3].

Haemodialysis machines or known as artificial kidneys were invented by Willem J. Kolff [4]–[6] in order for the patients to survive. Notably the machines are able to keep a failing kidney functioning till. There are two types' of dialysis namely haemodialysis (HD) and peritoneal dialysis (PD) [7]. Peritoneal dialysis are home dialysis, however in order to choose peritoneal dialysis the space needs to be very hygienic and clean. Thus, patients are more likely to choose haemodialysis instead. Despite haemodialysis being favoured, there are some cons of the HD namely filters known as dialyzer.

Firstly, dialyzer is too large that forces the patients to go to the hospital 3 to 4 times per week to undergo 5 hours of haemodialysis [8]. Secondly, the biomaterial of dialyzer needs to be improved to provide better results for the patients [9]. Up to this moment the existing dialyzer have caused some loss to proteins and other important substances [9]. Throughout the years, researchers have made improvements to the dialyzer by using nanoporous silicon membranes [7], [8], [10],

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[11]. Unfortunately, the silicon membranes [12] caused blockage of blood at the membranes that resulted in some waste not being filtered.

In this research dielectrophoresis (DEP) was applied to separate the particles such as red blood cells (RBC) from membranes to avoid the blockage [13], [14]. DEP is a movement of particles in non-uniform electric field due to time variation (AC) [15]. Frequency of electric field, particle shapes and sizes and particles' electrical properties are the main parts in DEP. Dielectric particles behave as an effective dipole, when dipole moment ρ, directly proportional to electric field E as shown in equation (1) [16],

$$\rho \alpha E \tag{1}$$

Directly proportional constant depends on the shapes and sizes of dielectric particles. When an electric field gradient is applied, force on dipole moment are as in equation (2)below [17], [18],

$$F = (\rho.d)\, E = k\, E \tag{2}$$

Where ρ is the dipole moment vector of constant, d is del vector, k is induced dipole moment and E is the external electric field. Constant k, in equation 2 was derived and shown as in equation (3) [16], [19],

$$F_{DEP} = 2\pi\varepsilon_{medium}\, R^3\, CMF\, (dE^2) \tag{3}$$

Where dE is the gradient rms electric field, r is the radius of particles and ε_m is the permittivity of medium. The main part in DEP is the Clausius-Mossotti factor (CMF) given by [16],

$$CMF = (\varepsilon_{particle} - \varepsilon_{medium}) / (\varepsilon_{particle} - 2\varepsilon_{medium}) \tag{4}$$

$\varepsilon_{medium\ and}\ \varepsilon_{particle}$ are the complex permittivity particles for medium and cells [15]. The CMF is calculated by using MATLAB, by finding the crossover frequencies, f_{ox} of red blood cells. CMF depends on electrical properties of particles and medium. Furthermore, DEP had been widely used to separate [20], manipulate [21], sorting and trapping [22] particles. Nonetheless, DEP have been used for live cells such as yeast cells [23], DNA [24], [25], cancer cells [26], leukaemia [27], red blood cells , proteins [28], [29] and etc. That is to say, DEP will be able to be used in artificial kidney. Two types of electrodes are used in this research, castellated and straight electrodes.

Aims of this research is to fabricate a 2D membrane with two different electrode design, which is the castellated and straight electrodes. Previous research had concluded that the castellated electrodes have higher electric field [30], [31]. Therefore, expected outcome from this research is the castellated electrode will shown faster movement of particles due to higher electric field produced by this electrode compare to straight electrode. Besides that, the aim is also to compare the time movement of particles on both electrodes.

2. FABRICATIONS

The first part in ths fabrication took place with standard cleaning to ensure the samples are clean from any impurities. There are two part of lithography, firstly are the membranes and secondly are the electrodes. This process was done by using positive resist, AZ1500. The membranes were design between 70-80μm size wise as shown in Figure 1a and 1b. Later, photoresist was spin coated for 40s to form a uniform resist. The resist is exposed by using mask aligner MIDAS SYSTEM, MDA-400LJ for 35s with a wavelegth of 365nm i-line. Then, silicon nitride was etched fully by using buffer oxide etching solution (BOE) for 10mins at 80°C.

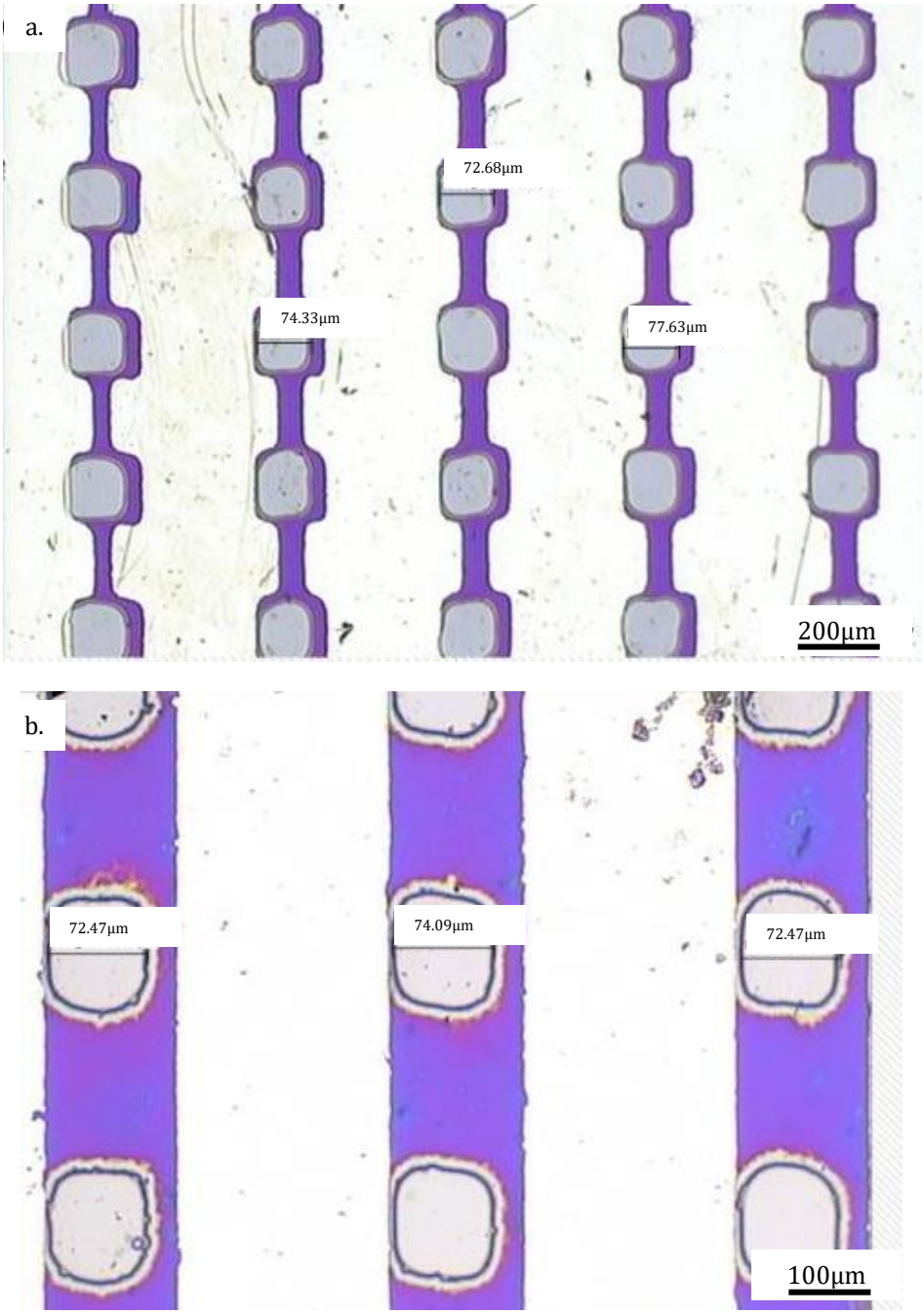

Figure 1. a. Membranes size for castellated electrodes b. Membranes size for straight electrodes.

Fabrication of both electrodes are shown in Figure 2. The fabrication of electrodes were divided into two parts, Figure 2a until Figure 2c are the first part of the lithography process, which are the membrane parts while Figure 2d and 2e represents the second part of fabrications which is the electrodes.

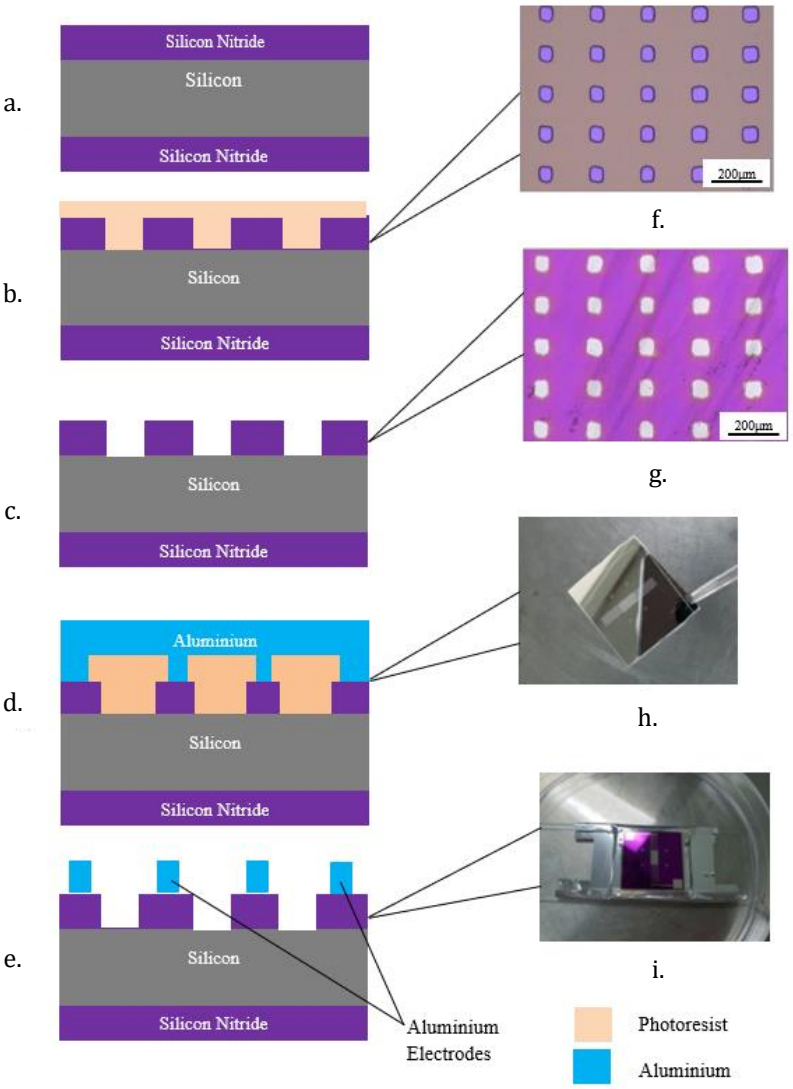

Figure 2. a. Silicon wafer covered with nitride on top and bottom, b. Lithography part for membranes, c. Silicon nitride was etched using BOE, d. Aluminium was sputtered on top of the sample, e. Lift of process to form electrodes, f. Membranes before etched, g. Membranes after etched, h. Aluminium deposited on top of the sample, i. The electrodes after lift-off took placed.

After that, the sample was deposited in 200nm thickness of aluminium. Aluminium later is lifted off for ≤10 minutes to form the electrodes structure. Electrodes were design around ± 150µm for straight electrodes and ± 218µm for castellated electrodes as shown in Figure 3a and 3b. Distances between the castellated electrodes are ± 35µm while for straight electrodes are ± 94µm as shown in Figure 3c and Figure 3d. In order to strengthen the structure of electrodes, aluminium electrodes were annealed for 30minutes with temperature of 180°C.

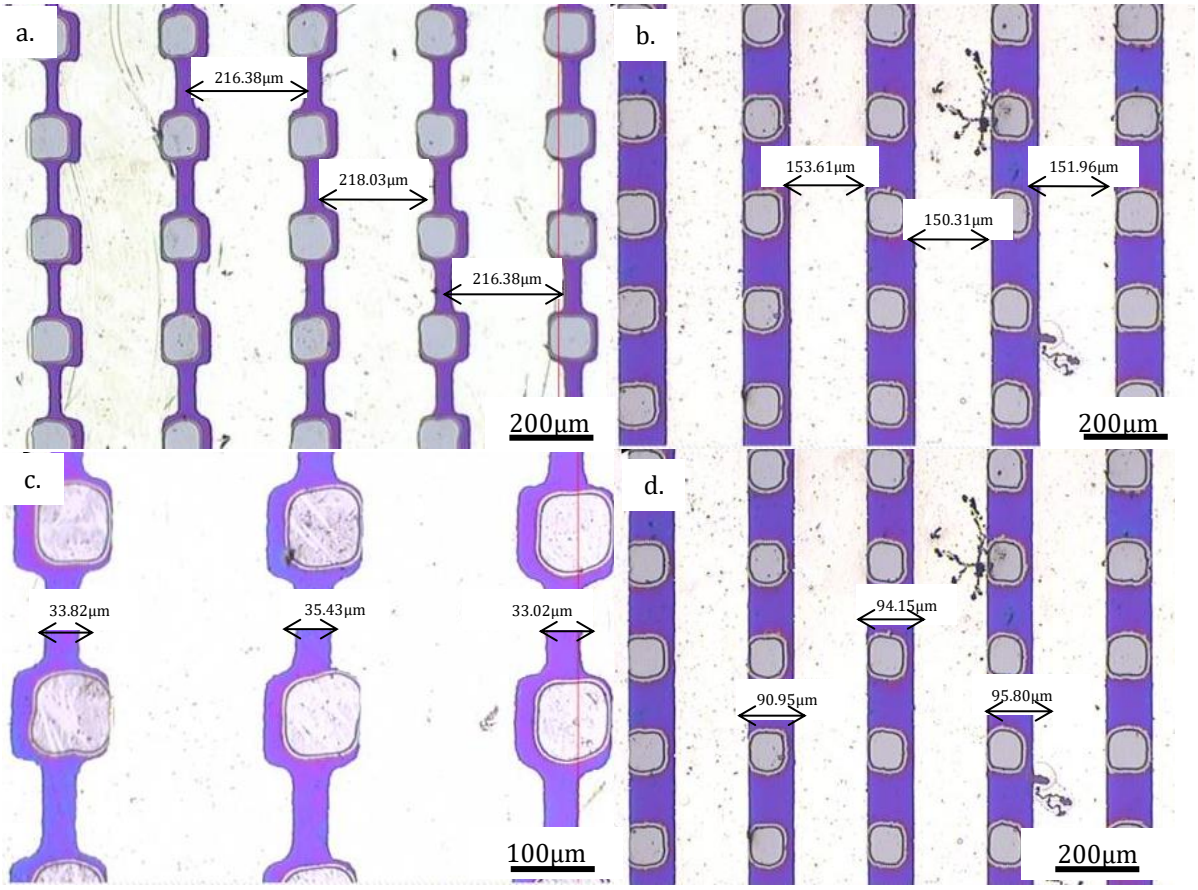

Figure 3. a. Castellated electrodes sizes, b. Straight electrodes sizes, c. Distance between electrodes for castellated design, d. Distances between electrodes for straight design.

Besides that, image using scanning electron microscope (SEM) of both castellated and straight electrodes are shown in Figure 4 below. Both electrodes were compared with magnification of x350 and x330 at 15kV. Image in Figure 4 also shows the differences of design using SEM for castellated and straight electrodes.

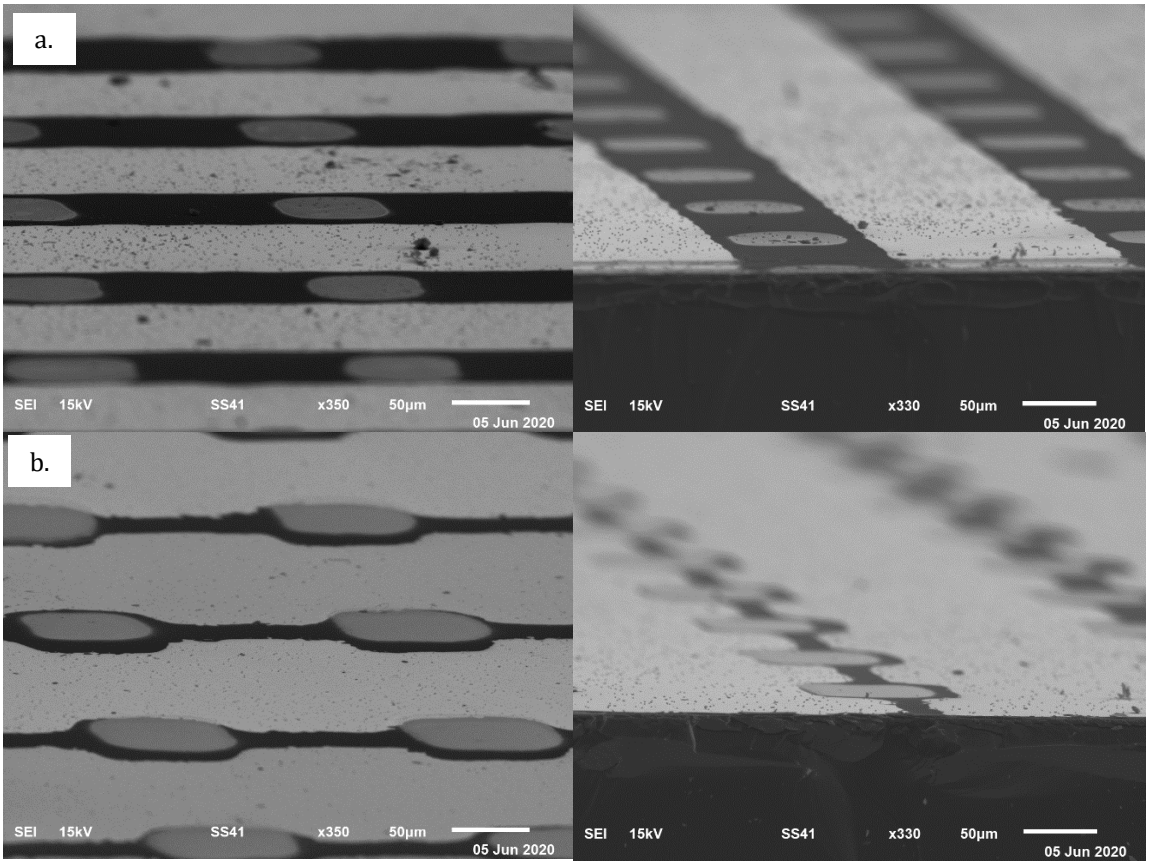

Figure 4. a. Straight electrodes using SEM, b. Castellated electrode using SEM; at 15kV with magnifcation at x350 and x330.

3. MATERIALS AND METHODS

The experimental setups are shown as per Figure 5. The electrodes were connected to a function generator. 10V potential was applied to the electrode, and another one was grounded. Electrodes were setup under Olympus Microscope (OM) to view the movement of AB+ red blood cells. Red blood cells (RBC) were drop on top of the electrodes and a glass slide cover was put on it. The RBC was mixed with 0.9% saline water to ensure the blood remains fresh. RBC was pinched by using diabetic pen with a safe procedure.

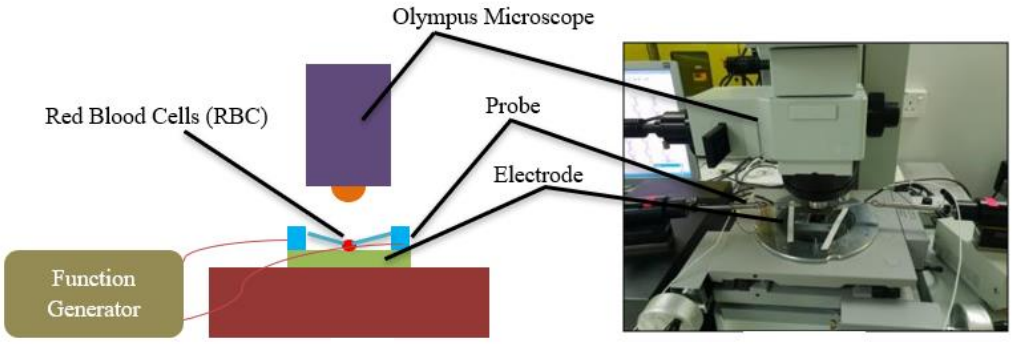

Figure 5. a. Illustration of experimental setup, b. Actual image of experimental setup.

This setup is to measure the particles frequency using DEP technique. The movement of particles were visual using the OM which were connected to the computer.

4. RESULTS AND DISCUSSION

Table 1 shows the average time (s) for the movement of red blood cells during positive DEP. Positive DEP is the main objective of this research, despite taken only one frequency. Most of the time, castellated electrodes caused the fastest movement of red blood cells. The red blood cells are somewhat tougher to control in term of movements because it had been mixed with saline water. It became much diluted, thus at 300kHz, 600kHz and 1MHz the results show that red blood cells on straight electrodes were much faster compared to the castellated electrodes. Nevertheless, overall results had shown that red blood cells at castellated electrodes show faster respond as compared to straight electrodes.

Table 1 Average time (s) for the movement of red blood cells

Frequency (kHz)	DEP respond	Castellated electrodes, Average time (s)	Straight electrodes, Average time (s)
100	Positive DEP	52	91
200	Positive DEP	53	62
300	Positive DEP	67	39
400	Positive DEP	61	65
500	Positive DEP	69	72
600	Positive DEP	47	34
700	Positive DEP	33	38
800	Positive DEP	50	65
900	Positive DEP	42	57
1,000	Positive DEP	87	50
2,000	Positive DEP	108	126
3,000	Positive DEP	129	134
4,000	Negative DEP	-	-
5,000	Negative DEP	-	-
6,000	Negative DEP	-	-
7,000	Negative DEP	-	-
8,000	Negative DEP	-	-
9,000	Negative DEP	-	-
10,000	Negative DEP	-	-
11,000	Negative DEP	-	-
12,000	Negative DEP	-	-
13,000	Negative DEP	-	-
14,000	Negative DEP	-	-
15,000	Negative DEP	-	-

The speed responds of particles is represent by the output time (s) in Table 1. The faster the responds the higher the electric field of the electrodes. Faster responds of particles automatically representing the movement of particles that will move away from the pathways which directed towards the electrodes and it is called as positive dielectrophoresis (Pdep). Intended responsed of particles in this research is to be attracted towards the electrodes (Pdep) in order to avoid any blockage during the filteration of RBC. Therefore, electrode with faster movement of particles will be much preferable to be used on the artficial kidney device, and the results are much shown by castellated electrodes.

2MHz and 3MHz are the obvious frequencies where particles start to respond slower than usual due to crossover frequency; (f_{ox}) (refer Equation (4)). The particles' f_{ox} were at 4MHz when

particles start shifting from positive to negative. CMF slowly decreased to 0 and showed slower movements of particles as shown in Figure 6. Figure 6 below shows a graph of CMF of RBC vs. the frequency (kHz).

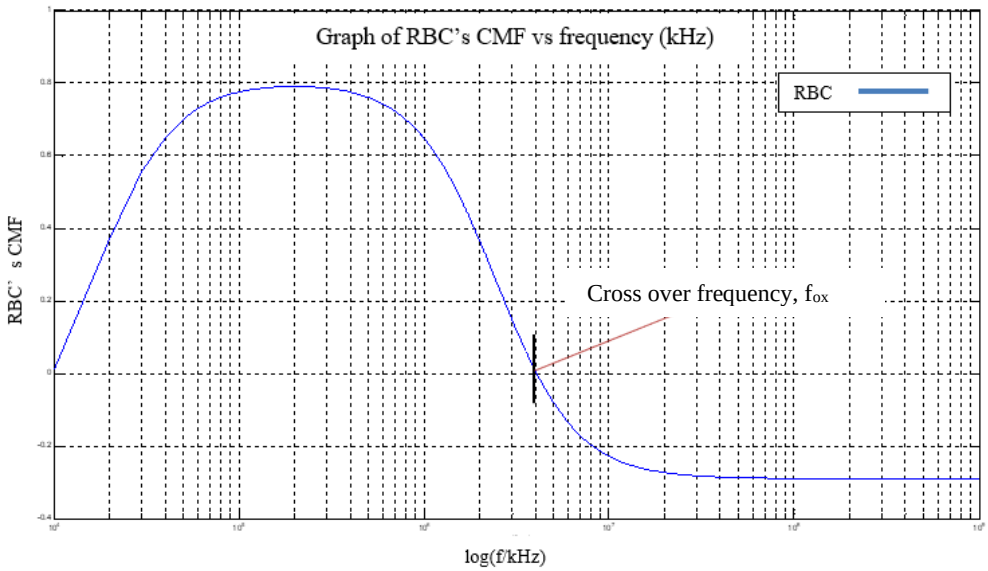

Figure 6. Graph of CMF vs frequency (kHz)100 kHz until 800 kHz are the best frequencies to study the movement of particles due to the very responsive particles.

Thereby, results of crossover frequency was done by using MATLAB R2014a software to find out the cross over frequency of the RBC.

5. CONCLUSION

In conclusion, it is proven that castellated electrodes provide better and faster result in clearing pathways containing RBC's from the membranes towards electrodes (Pdep). The output from previous research [30], [31] which resulted castellated electrode form higher electric field compare to straight electrode is also had been proven in this research. Therefore, by implementing DEP technique on the membranes, castellated electrodes are better to avoid blockage during the filtration process by artificial kidney device.

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