Segregation of blood cells using low powered di-electrophoretic field force

Rohit Dattatray Hegde
Student, Dept. of ECE
Canara Engineering College Mangalore,
India
hdrohithd@gmail.com

I. Abstract

Blood separation stands for the isolation of particles and cells that present in the blood. This is usually called as blood products. It includes red blood cells, white blood cells, plasma, and cryoprecipitate. Separation of whole blood into its blood products helps the patients to get only the necessary required part from whole blood. [1] The design in this paper gives the idea of the separation of platelets from whole blood using the di-electrophoresis principle. The device is designed in such a way that it separates platelets with the reduced power consumption of 2.5 volts. It also has the efficiency of 99.104% at the minimum time duration of 0.7sec. So, this design can be used to make an efficient blood segregation unit. The simulation of this design showed the successful separation of platelets with a high degree of accuracy.

Keywords: Di-electrophoretic, particle flow, platelets, Di-electrophoretic field

II. INTRODUCTION

Platelets are minute blood cells that help our body form clots to stop bleeding. If any damage occurs to the blood vessels, platelets rush to the damaged site and form a clot to prevent bleeding. They originate in the bone marrow along with white blood cells and red blood cells. Reduced platelet content in the blood leads to thrombocytopenia i.e. the condition where the bleeding can occur under the skin like a bruise, internal bleeding or unstoppable bleeding through a cut outside the body. Platelet reduction is mainly due to diminished production caused by viral infections, vitamin deficiencies, aplastic anemia, drug-induced, etc., and by increased destruction caused by idiopathic, pregnancy, immune system and by sequestration caused by an enlarged spleen, gestational. [2] The various technique which has been utilized for separation include centrifugal sedimentation, magnetic cell separation, fluorescence active cell sorting, etc. But they have the following disadvantages. Low purity, limited labeled with one marker at a time, expensive. So to overcome these problems, the proposed design is capable of isolates platelets from whole blood using very little electric power based on di-electrophoretic field flows fractionation. The blood particles get separated when a force is exerted on these particles when it is subjected to a non-uniform electric field. The blood need not be charged. Blood particles exhibit di-electrophoretic activity in the presence of electric fields and get segregated. [3]

III. STRUCTURAL ANALYSIS

A. Less powered di-electrophoresis:

When a neutral particle is made to move through a non-uniform electric field, the motion observed due to polarization effect is called di-electrophoresis. The electric field is created in the design by applying equal and opposite magnitude, less power electric potential for alternate electrodes. When the dielectric constant of a particle is more compared to the electrode medium system, the particle will be attracted to the electrode, which has the greatest field strength.

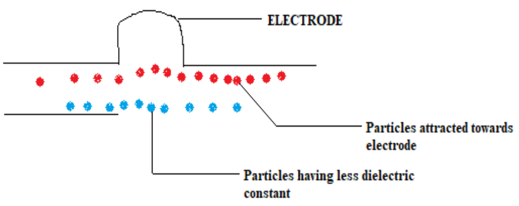


Fig.1. Di-electrophoresis simulation

By using the values from Fig.1 the force exerted by the particle is given by

$$f = (p \,.\, \nabla)E = 2\pi a^3 R\left[\frac{\varepsilon_1(\varepsilon_0-\varepsilon_1)}{(\epsilon_0+2\epsilon_1)}\right] \nabla E^2 [\mathrm{N}] \qquad [4]$$

P $\rightarrow$ induced dipole moment
E1 $\rightarrow$ permittivity of medium
E0 $\rightarrow$ permittivity of particle
a $\rightarrow$ area of electrode

So based on this property, the whole blood particles can be separated.

B. Geometry:

This design is mainly depending on a lab-on-chip device. It consists of inlet, outlet, and electrodes arranged alternatively with opposite polarity. Different geometry structures are designed and analyzed to get the optimized result.

IV. PETAL ELECTRODE T SHAPE

It consists of the inlet through which whole blood is made to flow and there are two outlets which are arranged in T structure, one for platelets and other for remaining whole blood. There are seven bulged, petal-like structure electrodes. For each alternate electrode, the potential of 2.5 volts is applied and for the in-between electrodes, equal magnitude negative voltages are applied. Due to this reduced electrical power, there is also a huge reduction in energy loss due to heating and electrochemical effect. Fig.2 symbolizes the petal electrode t shape.

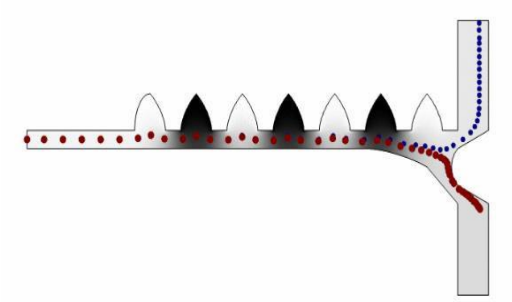


Fig.2 Petal electrode t shaped design

B. Numerical analysis

Numerical analysis of Fig.1 is done through software package COMSOL Multi physics. The width of the inlet is around 50um and the length of the channel till the end of the electrode is around 1300um. The height of the electrode is around 100um. For the whole blood, the inlet flow speed of 134um/sec and 2.5-volt electrical potential is required to segregate the platelets and the remaining whole blood. The below table gives the values of used parameters for RBCs and Platelets.

Cell	Density	Diameter	Conductivity
RBC	1050 kg/m^3	5um	0.31 S/m
Platelets	1050 kg/m^3	1.8um	0.25 S/m

Table. 1a. Analysis for petal electrode t shape

Relative permittivity	Shell electrical conductivity	Shell Relative permittivity	Shell thickness
59	1um	4.44	9e-9
50	1um	6	8e-9

Table. 1b. Continued analysis for petal electrode t shape

The electric heat loss for one electrode is as follows:

Potential applied: 2.5 volt
Time required for the separation of whole blood: 1.55 sec
Heat loss:

$$h = \frac{V^2}{R}t = \frac{2.5^2}{50}1.55 = 0.19375 \text{ J}$$

C. Observation

Due to platelet activation, negatively charged phospholipids from the inner to outer platelet membrane surface. Hence the surface membrane is negatively charged and which is attracted by the positively charged electrodes and thus gets segregated. The maximum efficiency is observed for flow rate of 134um/s and potential of 2.5 volt. This design is best suited to make the compact portable blood separation device

V. DOUBLE U SHAPE

It consists of inlet and there are two outlets. One for platelets and other for remaining whole blood. There are fourteen square cuts like structure electrodes. For each alternate electrode, potential of 8 volts is applied and for the in-between electrodes, equal magnitude negative voltages are applied. The path resembles double U structure. In this type of geometry, the whole blood undergoes several electric field forces through all these electrodes. So, this kind of geometry helps in efficient separation of platelets. Heat and electric loss is more when compared to petal electrode T shape. Fig.3 symbolizes the shape explained above.

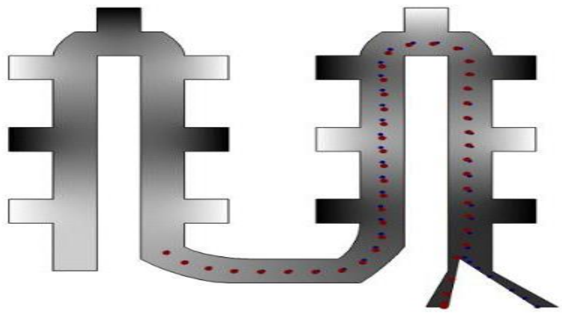


Fig.3 Double u shaped design

B. Numerical analysis

The width of the inlet is around 100um and the length of the channel is around 4400um. 8-volt electrical potential is needed to segregate the platelets and the remaining whole blood.

The electric heat loss for one electrode is as follows:
Potential applied: 8 volts
Time required for the separation of whole blood: 2.78 sec
Heat loss:

$$h = \frac{V^2}{R}t = \frac{8^2}{50}2.78 = 3.5584 \text{ J}$$

C. Observation

The maximum efficiency is observed for flow rate of 134um/s and potential of 8 volts for this design. Here the blood particles start segregating when the blood reaches nearly around

600um in the channel. When the whole blood starts to flow after 600um, the maximum separation of blood takes place.

VI. ELONGATED FORK SHAPE

It consists of inlet and there are two outlets, one for platelets and other for remaining whole blood. There are six square cuts like structure electrodes. For each alternate electrode, potential of 8 volts is applied and for the in- between electrodes, equal magnitude negative voltages are applied. The path resembles double elongated fork with 2 tines at the end structure. Elongated fork shape is showed in Fig 4 below.

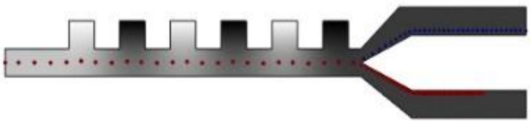


Fig.4 Elongated fork shape design

B. Numerical analysis

The width of the inlet is around 100um and the length of the channel is around 1900um. 8-volt electrical potential is needed to segregate the platelets and the remaining whole blood.

Potential applied: 8 volts
Time required for the separation of whole blood: 1.3 sec
Heat loss:

$$h = \frac{V^2}{R} t = \frac{8^2}{50} 1.3 = 1.664 \text{ J}$$

C. Observation

The maximum efficiency is observed for flow rate of 134um/s and potential of 8 volt for this design. Here the blood particles start segregating when the blood reaches nearly around 1400um in the channel. When the whole blood starts to flow after 1400um, the maximum separation of blood takes place.

VII. FLIPPED Y SHAPE

It consists of inlet and there are two outlets, one for platelets and other for remaining whole blood. There are seven square cuts like structure electrodes. For each alternate electrode, potential of 8 volts is applied and for the in-between electrodes, equal magnitude negative voltages are applied. The path resembles flipped Y shape at the end structure explained in Fig 5

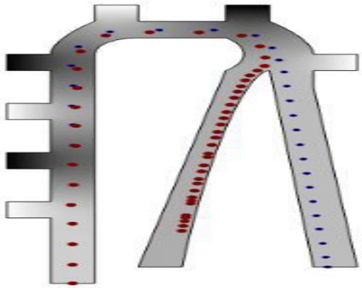


Fig.5 Flipped y shaped design

B. Numerical analysis

The width of the inlet is around 40um and the length of the channel is around 1650um. 8-volt electrical potential is needed to segregate the platelets and the remaining whole blood

Potential applied: 8 volts
Time required for the separation of whole blood: 0.7 sec
Heat loss:

$$h = \frac{V^2}{R} t = \frac{8^2}{50} 0.7 = 0.896 \text{ J}$$

C. Observation

The maximum efficiency is observed for flow rate of 134um/s and potential of 8 volt for this design. Here the blood particles start segregating when the blood reaches nearly around 450um in the channel. When the whole blood starts to flow after 450um, the maximum separation of blood takes place. Here both inlet and outlets are in y directional plane. Due to reduced width of the channel the whole blood start segregation just after passing 3 opposite polarized electrodes.

VIII. HORIZONTAL Y SHAPE

It consists of inlet and there are two outlets, one for platelets and other for remaining whole blood. There are 7 square cuts like structure electrodes. For each alternate electrode, potential of 6 volts is applied and for the in- between electrodes, equal magnitude negative voltages are applied. The path resembles horizontal Y shape at the end structure as shown in Fig 6.

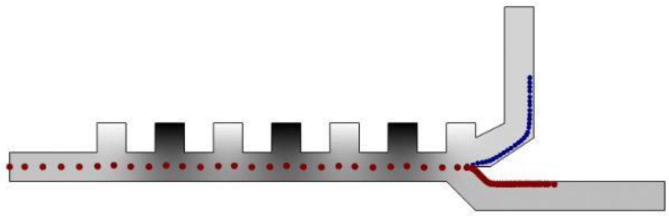


Fig.6 Horizontal y shaped design

B. Numerical analysis

The width of the inlet is around 100um and the length of the channel is around 2200um. 6-volt electrical potential is needed to segregate the platelets and the remaining whole blood.

Potential applied: 6 volts
Time required for the separation of whole blood: 1.55 sec
Heat loss:

$$h = \frac{V^2}{R} t = \frac{6^2}{50} 1.55 = 1.116 \text{ J}$$

C. Observation

The maximum efficiency is observed for flow rate of 134um/s and potential of 6 volts for this design. Here the blood particles start segregating when the blood reaches nearly around 1600um in the channel. When the whole blood starts to flow after 1600um, the maximum separation of blood takes place. Here both inlet and remaining blood outlets are in x directional plane and platelets outlet is in y directional plane.

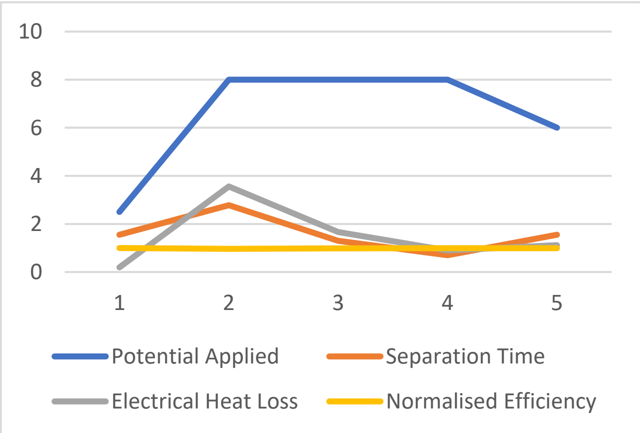
IX. RESULTS

Analysis of electric heat loss, efficiency, and the potential used to segregate whole blood and based on the length of the channel from which the blood start segregation, the best-suited geometry construction for better blood segregation can be found out. Here the reference impedance is taken as 50 ohms for all geometry and the minimum time is taken for the segregation is considered. The below Table 2 gives the idea to choose the best geometry based on their efficiency

Sl no	Geometry	Potential applied	Separation time	Electrical heat loss	Efficiency (based on heat loss)
1	Petal electrode T shape	2.5 volts	1.55 sec	0.19375 J	99.806%
2	Double U shape	8 volts	2.78 sec	3.5584 J	96.4416%
3	Elongated fork shape	8 volts	1.3 sec	1.664 J	98.336%
4	Flipped Y shape	8 volts	0.7 sec	0.896 J	99.104%
5	Horizontal Y shape	6 volts	1.55 sec	1.116 J	98.884%

Table.2 observed result

Graphical analysis for different geometries:



Graph.1 Graphical analysis

X. CONCLUSION AND FUTURE SCOPE

In this paper, the idea of using very less powered dielectrophoretic force field-based blood segregation is analyzed. In all these designs a non-uniform electric field is applied with the alternate change of polarity. [5] Among all these geometry structures, the petal electrode T shape design of 2.5-volt potential consumes very less energy and also heat loss is less. So this model is extremely suitable for portable devices for efficient separation of red blood cells and platelets. This technology makes the segregation of whole blood simpler and more efficient and it looks into the overall utilization of whole blood. The future scope of the paper is to practically build the device that will separate blood constituents efficiently and also in the designed voltage supply.

XI. REFERENCE

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