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A numerical study on the mixing quality of an electroosmotic micro-mixer with different angle internal fins

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Abstract: In devices with exact dimensions and low Reynolds number owing to limited flow, increasing the mixing quality is essential.

In this study, he focuses on increasing the effective parameters and their impacts on the mixing quality of a two-dimensional device (active micro-mixer) (active micro-mixer). This gadget mixes the two entering liquids with varying concentrations that enter the micro-channel from two separate inlets. 6 internal fins were positioned at various angles to the y axis

Four electrodes are also placed on the walls of the mixing chamber where the time-dependent electric field is applied, where the resulting electric force disturbs the parallel smooth flow lines, in addition to introducing the thermal physical property (joul heat) resulting from the magnetism generated by the electric current of the electrodes.

The governing equations are solved numerically using COMSOL Multiphysics 5.5a
Numerically active electro-micromixers have been investigated for various values of inlet velocity, frequency, and voltage.

The findings revealed that the quality of mixing relies significantly on the angle of inclination of the fins in the direction or opposite direction of the flow, where the angle of 45 degrees is the best, followed by the angle of 30 degrees, then 0, and the last angle comes -45 degrees.

The findings also indicated that the existence of vortices produced by the presence of fins makes the variations in mixing quality minimal and steady when utilizing the parameters of entrance speed, voltage, and frequency.

Keywords: Mixing Quality, Electroosmotic, Electric Field, Finite Element Method, Joul Heat.

Introduction:

Electroosmosis plays an essential part in many applications in microfluidics to produce controlled motions of tiny amounts of liquids. Electroosmosis is a process that happens on charged surfaces to create an electrical double layer (EDL)[1].

Increased interest in recent years in research based on on-chip laboratory technology for many diverse applications in biochemistry. Laboratory on a Chip is a high-precision factory that processes chemicals while combining typical operations such as mixing, filtration, separation, and detection onto a single chip[2].

During high Reynolds number flows, mixing may be increased by secondary and chaotic flows Alignment and eddies, but inside microfluidics (laminar flows), mixing relies on diffusion. Thus, in the technique utilized to enhance mixing, micro-mixers may be divided into active and passive. Active micromixers require an external power source for generating disruptions inflows, such as acoustic, vibration, and electromagnetic stimulation [3].

Efficient and fast mixing is essential for many microfluidic applications but is a difficult operation in many microfluid systems conducting complicated chemical analysis and synthesis. Most existing microfluidic mixing methods are restricted to low Reynolds number systems. According to the scaling rule, decreasing the mixing route may reduce the mixing time and enhance the mixing quality.

Therefore, it is essential to know the mixing process inside the fine crushing machine. To accomplish this, one must be able to explain and assess the performance of mixing and its practical consequences[4].

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To disrupt the flow of external energy by using different techniques such as electrophoresis, electrophoresis, or the electrochemical pulse and magnetic and heat fields. Despite the increase in mixing efficiency, this kind of micromixer is the most difficult to operate and build. While passive micromixers do not require an external actuator to be able to improve mixing efficiency by altering their shape to produce convection not only for foldability and expansion of the interface between liquids but for the goal of optimization as well [5].

In this article, we mix two liquids with varying concentrations and similar physical characteristics.

The micromixer consists of a microchannel with a rhombic mixing chamber and the presence of internal fins with various angles to the y-axis. Four time-dependent sinusoidal electrodes were put, electric fields were created on the walls of the mixing chamber to increase the mixing rate. mixing efficiency.

Description of the problem:

Figure (1) illustrates the fine mixing equipment utilized in this study. It consists of a straight channel with 6 fins that form an angle with the y axis. Where 4 various angles (0, 30, 45, -45) figure (2) were obtained and the difference between them was examined. The model also contains a rhombus mixing chamber to form vortices and thus improve the mixing ratio, as the liquid flows through two different inlets, and the sinusoidal electric field is shed within four electrodes installed on the walls of the mixing chamber, as Figure (3) shows the channel dimensions. The liquid employed has properties comparable to those of water(relative permittivity of $\varepsilon r= 78.3$, a conductivity of an ionic solution of $\sigma=0.11845$ S/m, and a diffusion coefficient of D = 1× 10^(-11) m^2 /s). The mixing quality is tested between the previous four instances and the best one is chosen by the usage of certain factors such as the frequency of the current, the entrance velocity of the liquid.

This work aims to produce a sample of excellent mixing quality for the liquids used in the shortest feasible time and the least expense and effort to be utilized in the different areas of inspection and to get accurate findings.

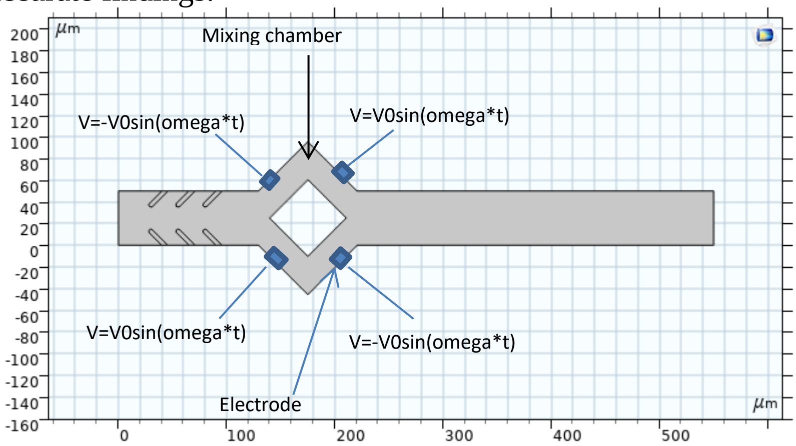

Figure (1) Representation of mixing chamber details

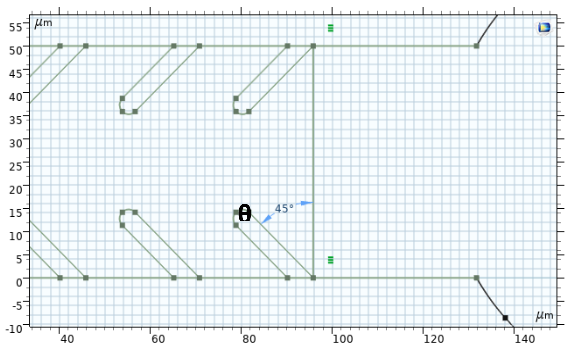

Figure (2) Representation of Fin tilt angles

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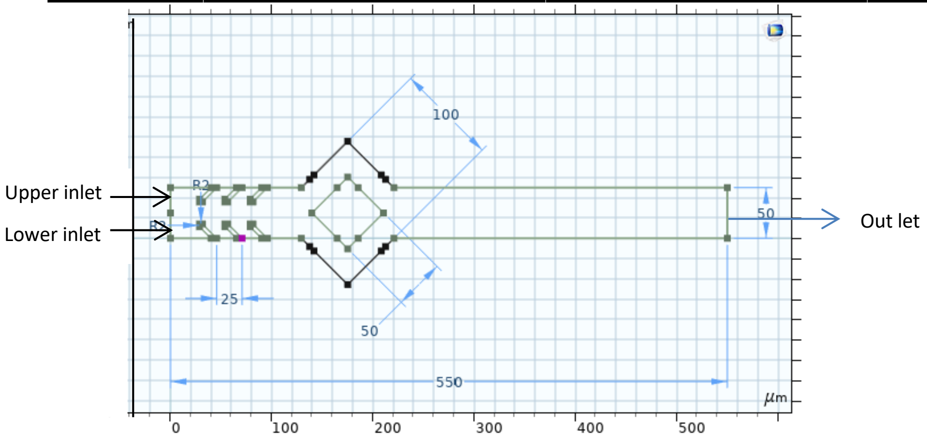

Figure (3) Representation of Dimensions of the model used

Governing Equations

In this study, the equations (flow field, electric field, electromagnetic field, Concentration field, and mixing quality):

Flow Field:

The flow is creepy and we assume that the fluid flow is incompressible and Newtonian, therefore, obeys the laws of continuity and momentum:

$$\rho\frac{\partial \mathbf{u}}{\partial t} = \nabla\cdot[-p\mathbf{I} + \mathbf{K}] + \mathbf{F} \quad (1)$$

$$\rho\nabla\cdot\mathbf{u} = 0 \quad (2)$$

$$\mathbf{K} = \mu\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) \quad (3)$$

where p is the fluid density (kg/m3), u denotes the velocity field with the x-axis (m/s), P is the pressure (Pa), F refers to fraction factor(0) and I refer to an Identity matrix.

Boundary conditions: the entry velocity is the same, and the normal pressure is not applied at the entrance and exit of the channel, and there is slippage at the walls, which is shown by Equation (4)

$$\mu_{eo} = -\frac{\epsilon_r\epsilon_0\zeta}{\mu},\quad \mathbf{E}_t = \mathbf{E} - (\mathbf{E}\cdot\mathbf{n})\mathbf{n} \quad (4)$$

Where µ the dynamic viscosity (Pa . s), εrε**0** denotes the fluid's electric permittivity (F/m), ζ represents the zeta potential (-0.1 V), and E the electric field (V/m).

Electric Field :

The equations related to the electric field and their boundary conditions, where the equations are subject to Ohm's law and the equilibrium equation for current density, are included as follows:

V = V0*sin(omega*t) (5)

$$\nabla\cdot\mathbf{J} = Q_{j,v} \quad (6)$$

$$\mathbf{J} = \sigma\mathbf{E} + \mathbf{J}_e \quad (7)$$

$$\mathbf{E} = -\nabla V \quad (8)$$

Omega = 2*л*f (9)

where V0 is the amplitude of the AC potential with a value of 1V and f refers to the frequency(4 Hz), σ the electrical conductivity and σ**E** refer to current density (A/m2). The boundary conditions are the time change with the sinusoidal shape and are applied to the electrodes as shown in equation (5).

2-3- electromagnetic field :

This section contains the equations related to the magnetic field arising from the passage of electric current at the poles:

 ISSN NO: 2770-0003
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$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q_e \quad (10)$$

Where Cp is the heat capacity at constant pressure(m^2.K/s^2), K refers to Thermal conductivity(W/(m. K)), Qe refers to the heat equivalent (watt), and T the temperature.

Concentration field :

This section contains equations related to the concentration of the liquid used and the boundary conditions used in it, as shown in the following:

$$\nabla \cdot \mathbf{J}_i + \mathbf{u} \cdot \nabla c_i = R_i \quad (11)$$

$$\mathbf{J}_i = -D_i \nabla c_i \quad (12)$$

where the **J**i is the mass flux, Ci is the initial concentration, Di denotes the diffusion coefficient (1e-11 m^2/s).

In boundary conditions, we assume that in the upper half, the liquid enters at a concentration of C = 1 mol/m^3, As for the lower half, the liquid enters the concentration C = 0 mol/m^3. At the outlet, the convection is present, so at the outlet, we assume that there are no boundary conditions and as in the equation (13)

$$-n. Ji = 0 \quad (13)$$

Mixing Quality:

The equations governing mixing are used in this section to determine the quality of mixing. The MQ factor used in the literature is determined using the following equations:

$$MQ = (1-\sqrt[2]{(Xmean^2/Xmax^2)})\times 100 \quad (14)$$

$$\mathbf{X}mean^2 = \int (Ci - Cmean)^2 dy \quad (15)$$

This integral is applied to the grid points at the outlet," Ci is the concentration (mol/m^3). at point i, and Cmean is the mean mixing concentration (mol/m^3). Xmax equals to the maximum concentration variation in the mixture". The closer the mixing ratio is to 100%, the better the mixing, while if it approaches 0%, the worse the mixing.

Mesh:

A mesh of irregular integrated triangular geometries is used as shown in Figure (3) where it shows the nature of the network formation near the wall at entrances and exits and near the fins as well as near the electrodes where they are found with gradient density, as Table 1 shows the details of the mesh.

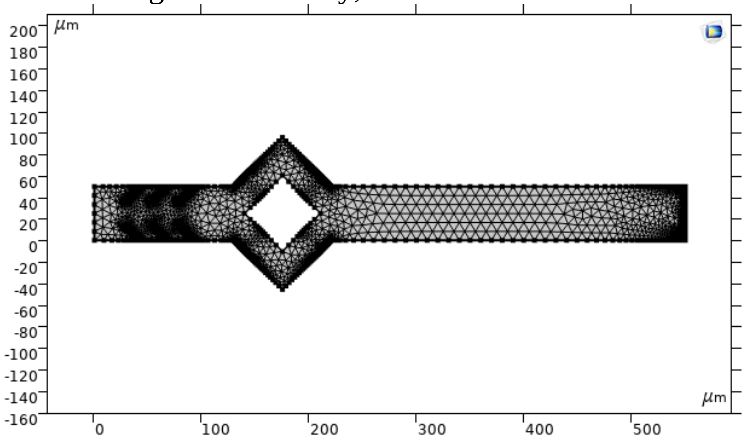


Figure (4) Representation of the mesh distribution

Table (1) the values of details the mesh

cases	Number of elements	the number of vertex elements	Number of boundary elements	Minimum element quality
Fins at 0 deg	9104	57	970	0.5078
Fins at 30 deg	9108	57	984	0.4769

 ISSN NO: 2770-0003
Date of Publication: 13-11-2021

Fins at 45 deg	9064	57	980	0.5031
Fins at -45 deg	9156	57	976	0.4981

Validation:

The validity of the simulation work was confirmed by comparing the numerical results of our present work with the numerical results of Habib Jalili et al[1]. Where the percentage of deviation was (0.5%) approximately, as shown in figure(4)

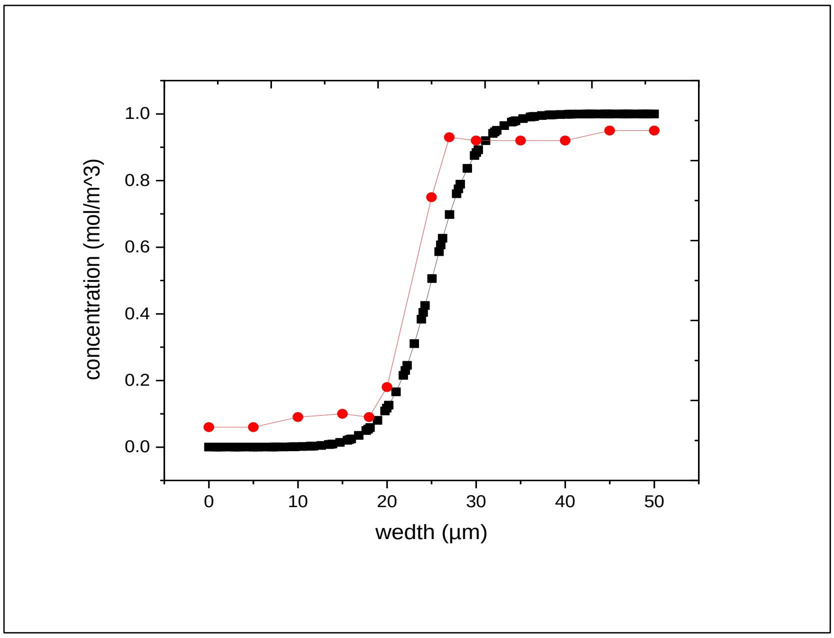
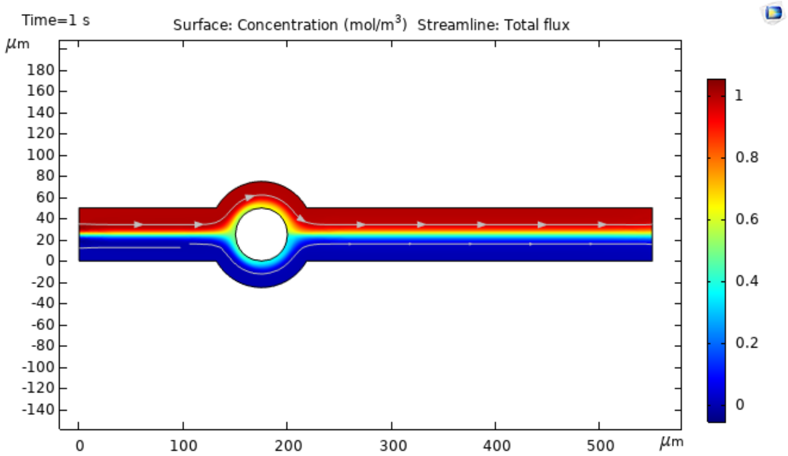


Figure (4) Representation of The difference between Habib Jalili's report and my work

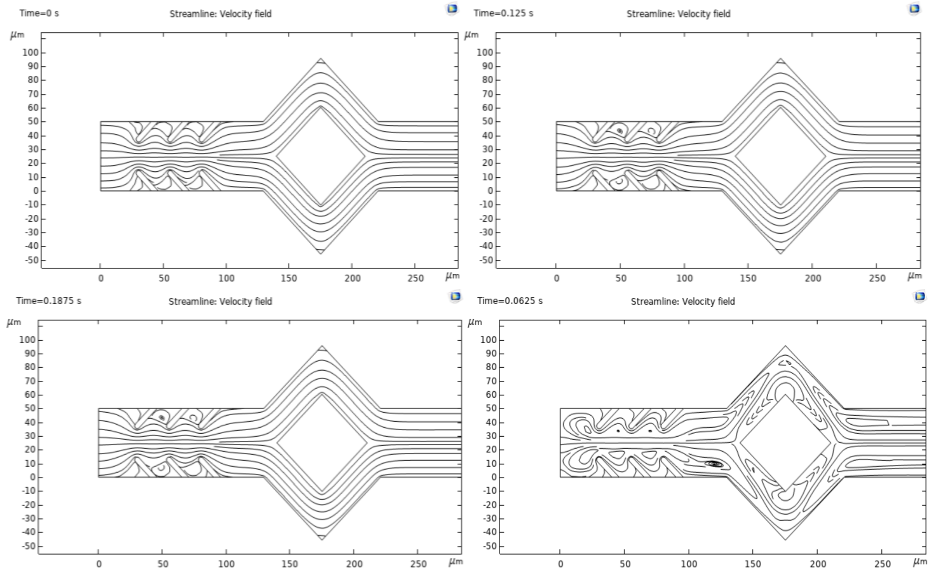


Figure(5) Representation of the streamline at t = 1 s

The mixer is taken with a circular mixing chamber as shown in Figure (5), where the mixer enters a liquid from two different inlets with different concentrations, and they are collected in a circular mixing chamber, where the simulation was carried out under conditions (inlet velocity 200 um/s, voltage 1V, zeta potential -0.1V, frequency 4 Hz).

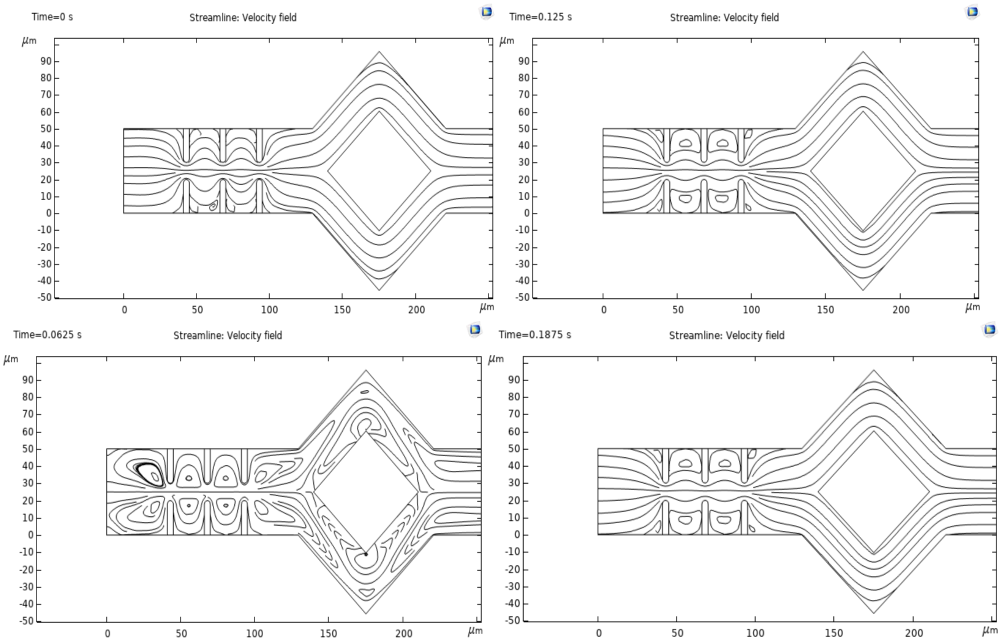
Result and Discussion:

The use of the time-dependent sinusoidal electric field, as well as the usage of a rhombic mixing chamber as in Figure (1), assist in the creation of vortices within the liquid and therefore improve the mixing efficiency in an electric micro-mixing device, as demonstrated by (Habib Jalili at el) [1] and we have done our part by adding Fins at various angles (0, 30, 45, -45) with the y-axis as in Figure (2) to determine the optimum angle that enhances the quality of mixing by utilizing the speed of entering the liquid into the micromixer. Mixing by raising the temperature of the liquid by use of magnetism produced by the passage of electricity in the electrodes.



Figure(6): Representation of Streamlines at the rhombic formation obstacle in the mixing chamber one-cycle sine curve for (V0 = 1 V, F = 4 Hz, zeta = -0.1 V, θ = 45˚ with y axis)

Figure (6) shows the intensity of the vortices forming at four time periods, as they were the sharpest and most effective in raising the quality of mixing than the other angles.



Figure(7): Representation of Streamlines at the rhombic formation obstacle in the mixing chamber one-cycle sine curve for (V0 = 1 V, F = 4 Hz, zeta = -0.1 V, θ = 0˚ with y axis)

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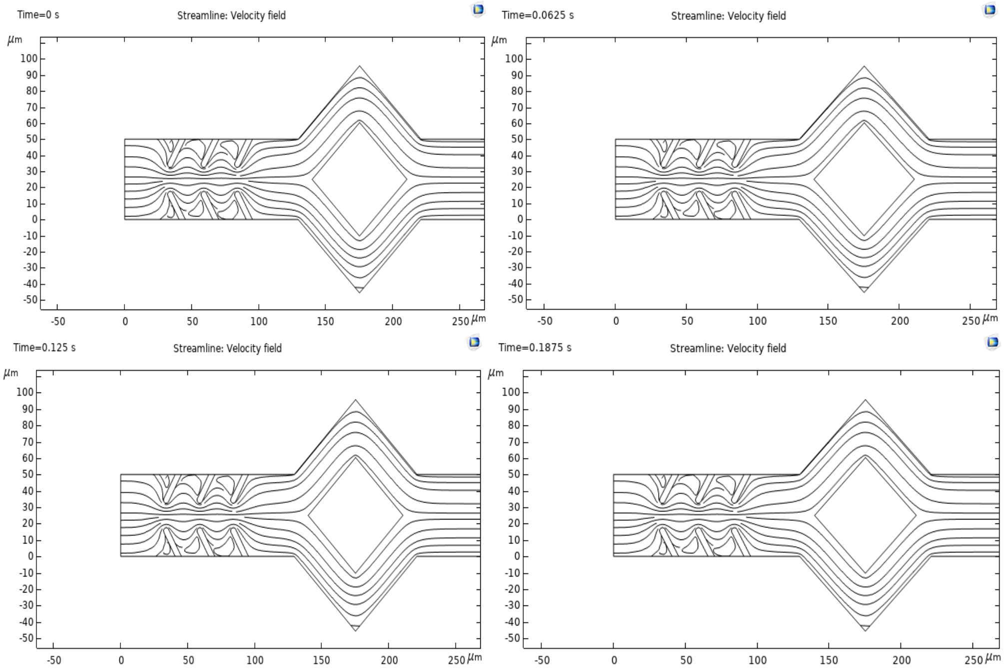
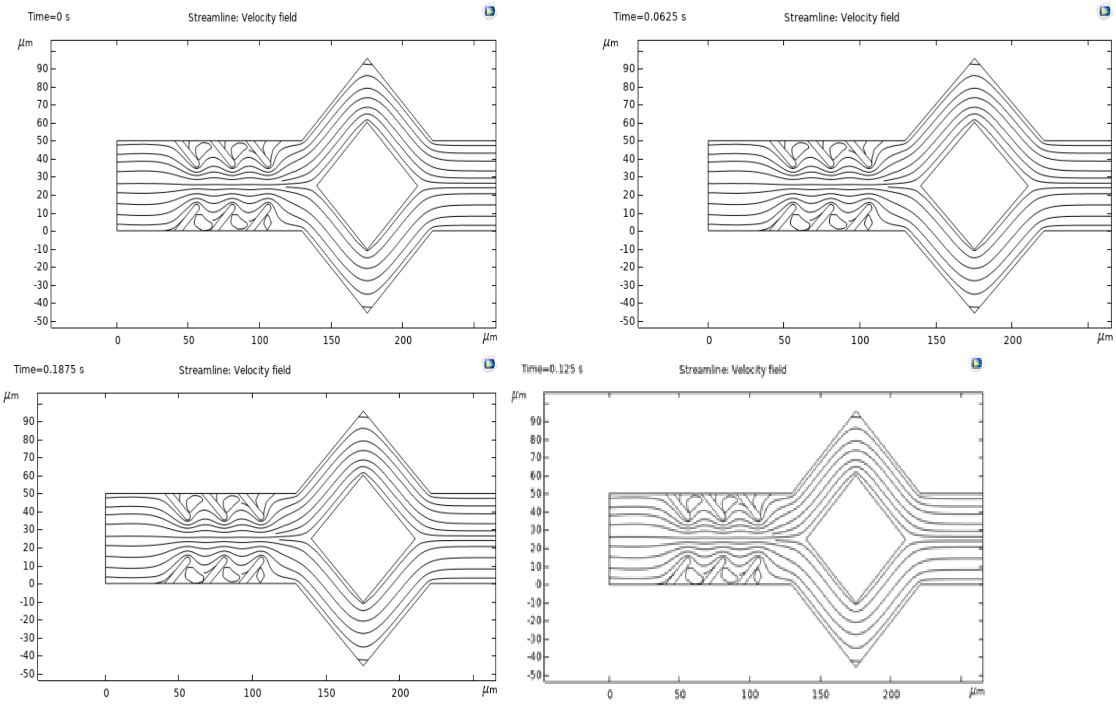


Figure(8): Representation of Streamlines at the rhombic formation obstacle in the mixing chamber one-cycle sine curve for (V0 = 1 V, F = 4 Hz, zeta = -0.1 V, θ = 30˚ with y axis)



Figure(9): Representation of Streamlines at the rhombic formation obstacle in the mixing chamber one-cycle sine curve for (V0 = 1 V, F = 4 Hz, zeta = -0.1 V, θ = -45˚ with y axis)

The figures are shown in (6,7,8,9) show how the vortices are formed inside the sample with the different angles of the fins used in them, where the most effective vortices are when using the fins at an angle (45).

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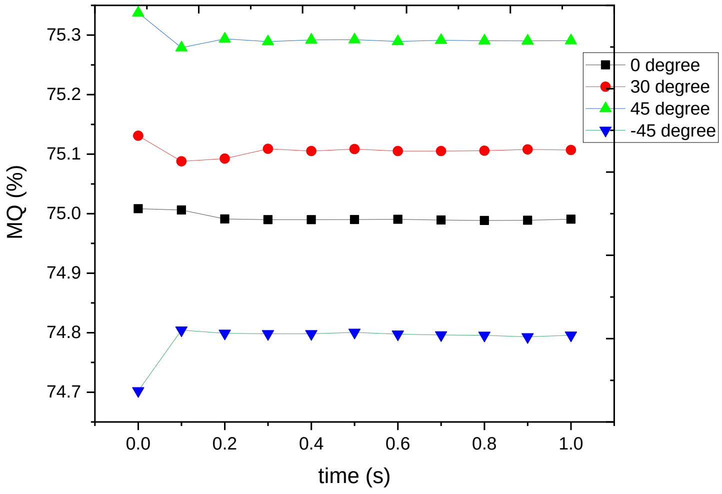
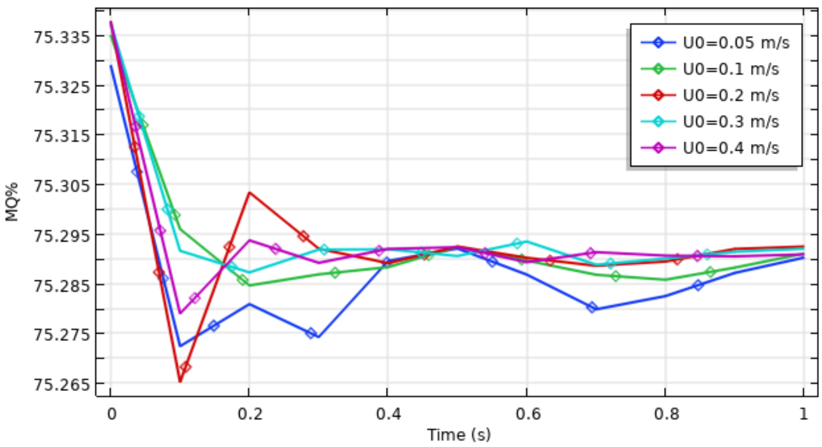


Figure(10): Representation of Comparison of four cases of different fin angles with the y-axis in terms of study state of velocity (U0=0.2 mm/s).

The figure(10) shows a clear preference in the mixing ratio of the fins tilted at an angle of 45 degrees with the y-axis counterclockwise over the other cases and by a difference (0.2%) over the next case, which is the inclination of the fins at an angle of 30 degrees.



Figure(11): Representation of MQ with time for multi-velocity for a best-case

Figure (11) shows the mixing quality for several speeds over time, noting that there is no significant difference to form the vortices that help in the stability of the mixing quality with a slight advantage to the speed 0.2 mm/s.

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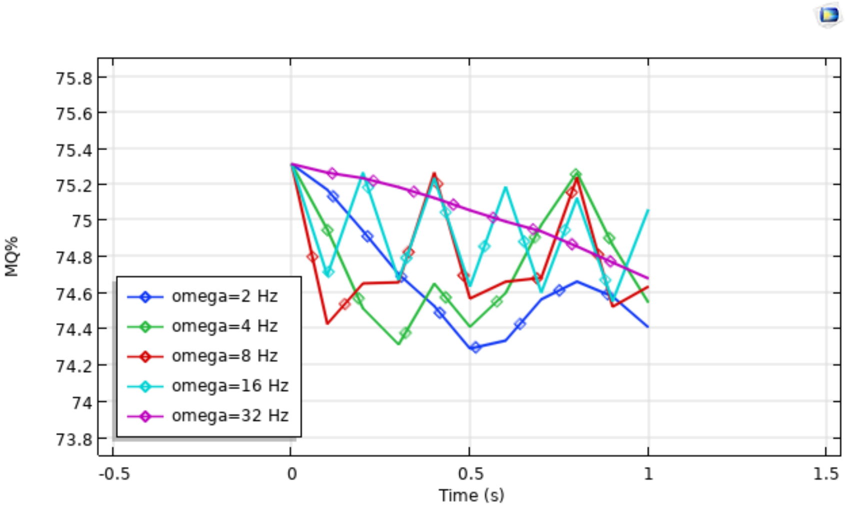
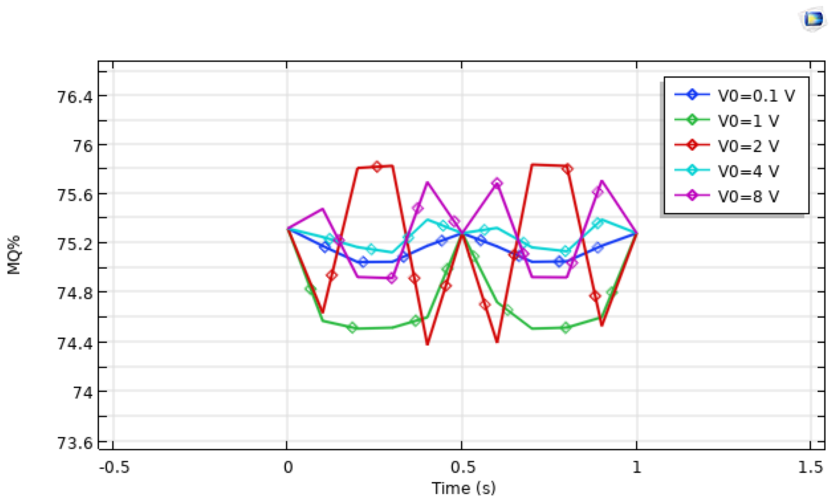


Figure(12): Representation of MQ with time for multi-frequency for a best-case

Figure (12) shows the mixing quality for several frequencies over time, as the 4 Hz frequency takes priority, noting the stability of the mixing quality as the frequency increases.



Figure(13): Representation of MQ with time for multi-voltage for a best-case

Figure (13) shows the quality of mixing for several volts over time, as 2 volts takes precedence over the rest of the values.

Conclusions:

In this research, an electrically micro-mixing device was designed that contains a rhombic mixing chamber for the advantage it has as proven (1) whereby an electric voltage is installed on the wall of the mixing chamber and the thermophysical property resulting from the magnetism generated by the electrodes was introduced, and fins were placed as obstacles To generate vortices to help improve the quality of mixing, as proved by (2) where the angle of inclination of the fins was changed with the y axis and depending on the entry velocity of the liquid, frequency, and voltage to find the mixing quality, the following was reached:

* There is a clear preference for fins inclined at an angle of 45 degrees with the y-axis (counterclockwise) where the mixing quality was 75.3 percent, followed by fins inclined at an angle of 30 degrees with a mixing quality of 75.1 percent, while the fins at an angle (0 and -45) had the mixing quality lower, respectively. (75 percent and 74.8).

* The difference in the velocity of entering the liquid affects the quality of the mixing, as the entry velocity was 0.2mm/s is optimal for this model depending on its shape and its variables, as the fins obstruct the flow of the liquid and thus the vortices have a different intensity depending on the speed of entering the liquid where the more severe it is Without altering the flow, it provides priority and stability to the quality of the mixing, which in turn assists in enhancing the quality of the mixing.

ISSN NO: 2770-0003
Date of Publication: 13-11-2021

* The best frequency achieved is 4 Hz with a mixing quality of 75.28 percent This relies on the shape of the model and the current physical properties.
* The best voltage achieved is 2 V at a mixing quality of 75.8 percent It also relies on the geometric form of the model and the physical characteristics that are supplied.

References:

1. Habib Jalili1, Mohammad Raad2, and Davoud Abbasinezhad Fallah, "Numerical study on the mixing quality of an electroosmotic micromixer under periodic potential, 2020" Department of Chemical Engineering, Urmia University of Technology, Iran. DOI: 10.1177/0954406220904089.
2. Panta Y.M, Lin W, Aryal S., and Adhikari P, 2012 "Technical Brief: Numerical Analysis of Magnetohydrodynamic (MHD) Flow in Microdevices", Journal of Biomedical and Bioengineering, ISSN: 0976-8084, pp. 86-89, USA.
3. Pouya Mehrdel *, Shadi Karimi, Josep Farré-Lladós and Jasmina Casals-Terré, 2018 "Novel Variable Radius Spiral–Shaped Micromixer: From Numerical Analysis to Experimental Validation" Universitat Politècnica de Catalunya, Colom 7-11 08222 Terrassa, Barcelona, Spain.
4. H. S. Seo and Y. J. Kim, 2011 "Numerical Study on the Mixing Performance of Ring-Type Electroosmotic Micromixer with Configurations of Obstacle in the Mixing Chamber" Sungkyunkwan University, Sungkyunkwan University, Korea. ISBN978-1-4398-7139-3.
5. Farahinia1. W. J. Zhang1, "Numerical analysis of a microfluidic mixer and the effects of different cross-sections and various input angles on its mixing performance" Journal of the Brazilian Society of Mechanical Sciences and Engineering, (2020) 42:190.

Appendix

Notation

AC	alternative current
Di	diffusion coefficient (m2/s)
f	frequency (Hz)
j	mass flux (kg/(m2 . s))
MQ	mixing quality
p	pressure (Pa)
U	velocity vector (m/s)V potential (V)
V0	voltage amplitude (V)
τ	kinetic viscosity (m2/s)
εr	fluid relative permittivity
εw	fluid electric permittivity (F/m)
θ	angle of the fin with the y-axis
ζ0	zeta potential (V)
σ	conductivity of the ionic solution (S/m)