Comparison and Analysis of Efficient Heating of Blood Sample in Microwave at the Intensities of 2.5 W-cm^{-2} and 3 W-cm^{-2} in Presence of Suitable Support at the two different Microwave Frequency of 2450 MHz and 915 MHz.

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Abstract: The use of microwave is growing enormously due to its volumetric heating method. Volumetric heating method is a pollution free technique, which is used for heating the complete volume of the continuous liquids, semi-solids etc. Microwave energy has a wide range of applications which encompasses everything from heating, thawing to material processing and drying. Heating/Warming of blood is a very usual and regular practice in our medical industry and microwave heating can be efficiently used for this purpose due to its selective, rapid, controlled and uniform heating. This work has been carried out to compare the efficient heating of 1-D blood sample placed on a layer of metallic and composite supports at the intensities of 2.5 Wcm^{-2} and 3 Wcm^{-2} processed in microwave at two different microwave frequency of 2415 MHz and 915 MHz with the support thickness of 1.5 mm. An introductory study has been carried out to find the power absorption within the blood sample for the various cases by plotting the average power vs sample thickness diagram. It is observed in the study that microwave power absorption is elevated for the consecutive R1 and R2 modes of significant magnitude for the suitable support thickness. It is found that the efficient heating of blood is signalized by the large heating rate with the uniform temperature distribution within the blood samples (minimal thermal runaway).Also the heating at the intensity of 2.5 Wcm^{-2} is compared to the heating at 3 Wcm^{-2} intensity.On basis of the comparisons and investigations suitable supports, support thickness, intensity of the heating is recommended as the most favorable heating conditions for blood samples.

Keywords: Thermal Runaway, Microwave Heating, Blood, Composite Support, Resonances.

1. INTRODUCTION

Microwave have the electromagnetic radiation in the range of 300 MHz to 300 GHz frequency. While the microwave heating of the blood, the electrical energy is converted into heat due to the dielectric loss which is the function of frequency of MWs.Volumetric heating effects in microwave causes the localized and non-uniform heating in samples. MW propagation helps in analyzing the resonance which occurs only for specific dimensions of 1D slabs and 2D cylinders. Due to the resonances MW heating are also applied for thawing and heating of multiphase systems and greater rates in material processing.

At present, very few work has been carried out for the processing of a multiphase system like blood samples etc. In medical practices, in blood bank, blood samples (whole blood) is kept at low a temperature of 1 to 6 ^{o}C which has a storage period of 2-4 weeks. If the blood sample has to be kept for a longer period (more than a month), then blood samples need to be preserved at a very low temperature of -30 to -65 ^{o}C. Before blood transfusion it is imperative to heat/warm the blood sample. In emergency situations, orthodox methods for warming the blood may not be useful as it takes several hours for heating. In this case, the use of microwave for blood sample warming/heating seems to be an efficient technique as it takes less than a minute for the processing of the blood samples.

In this work we have compared the effective heating of the blood samples in the shape of 1D slabs placed in the different supports in the presence of resonances placed in the different metallic and composite supports of 1.5 mm for the microwave frequency of 915 MHz and 2415 MHz at 2.5 Wcm^{-2} intensity. During the warming of the blood samples, the power absorption during resonances is affected by the power which is absorbed by the sample in the presence of various support.

Evaluation of electric field and power in microwave transport in a multilayered sample:

A schematic illustration of the heating characteristic of the blood sample placed in the metallic or composite support is shown in fig 1.

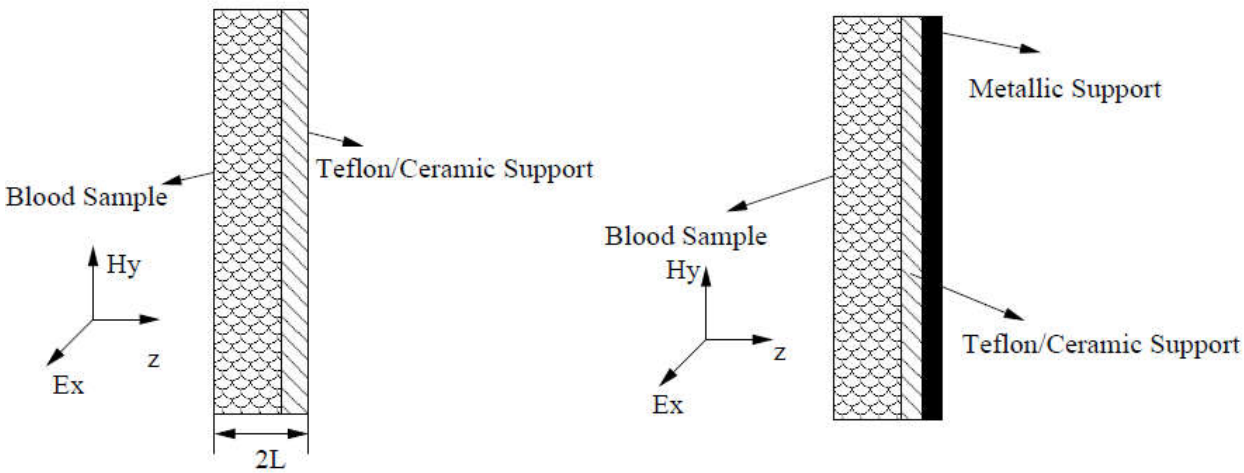

Figure.1: Illustrative view of Blood Sample placed in the various supports which is exposed to the Electromagnetic Waves.

The equation given by Maxwell on the electromagnetic wave propagation caused by uniform electric field E_x is:

$$\frac{d^2E_x}{dz^2} + \kappa^2 E_x = 0 \qquad (1)$$

Here, E_x is varying in the direction of propagation z axis and lies on x-y plane. In eq. 1,

$\kappa = \frac{\omega}{c}\sqrt{\kappa' + i\kappa''}$ is the propagation constant which depends on the dielectric constantκ' and the dielectric loss,

κ" ,ω= 2π f , where f is the frequency of the electromagnetic wave and c is the velocity of light.From eq. 1, the electric field for the l^{th} layer in a multilayered sample obtained is:

$$\frac{d^2E_{x,l}}{dz^2} + \kappa_l{}^2 E_{x,;} = 0 \qquad (2)$$

Where $z_{l-1} \leq z \leq z_l$ and l = 1…n. Supposing that each layer has a constant dielectricproperties, the general solution of the eq. 2 represented as a linear combination of transmitted and reflected waves propagating in the opposite directions is:

$$E_{x,l} = E_{t,l}e^{iK_l z} + E_{r,l}e^{-iK_l z}, \quad z_{l-1} \le z \le z_l$$

$$E_{x,n} = \begin{cases} E_{t,l}e^{iK_l z} + E_{r,l}e^{-iK_l z}, & z = z_n\ (air) \\ 0, & z = z_n\ (metallic) \end{cases} \qquad (3)$$

Where $E_{t,l}$ and $E_{r,l}$ are coefficients due to transmission and reflection, respectively. Cofficients, $E_{t,l}$ and $E_{r,l}$are obtained by solving the set of algebric equations and using the general solutions(eq. 3) and suitable boundary conditions at the interface. Poynting vector theorem is used for obtaining the absorbed power in the l^{th} layer. i.e.

$$q_l(z) = \frac{1}{2}\omega\varepsilon_0\kappa''_{eff}E_{x,l}(z)E_{\ x,l}\ (z)$$

Here ε_0 is the free space permittivity, and $\kappa''_{eff}$is the effective dielectric loss. Effective dielectric properties of blood are obtained from the literature. The average power can be obtained from the integration of the power across the slab. i.e.

$$\overline{q} = \frac{1}{2L}\int_{-L}^{+L} q_l(z)dz \approx \frac{1}{2L}\sum_{z=0}^{2L} q_l\ (z)$$

Where, -L and +L denote the left and right faces of the slab respectively and $q_l(z)$denotes the power as a functionof z, wherez is measured from the left edge of the slab orsample assembly. The thickness of the entire slab is 2L. We denote L_s as the thickness of the sample and L' as the total thickness of supports such that $2L=L_s+L'$.

The average power for a sample of thickness L_s is:

$$q_{av} = \frac{1}{n}\sum_{i=1}^{n} q_l(z_i), \qquad for\ 0 \le z_i \le L_s \qquad (6)$$

The energy balance equation due to microwave assisted heat source is:

$$\rho c_p\ \frac{\partial T}{\partial t} = k\ \frac{\partial^2 T}{\partial z^2} + q(z) \qquad (7)$$

Where,$\rho, c_p$and k are specific heat, effective density and thermal conductivity, respectively. Finite element method can be used to solve the eq 7.For all the simulation and computation dielectric properties and thermal properties of blood sample at 2450 MHz and 915 MHz are obtained from the literature. The simulation work at these two frequencies are compared at intensity 2.5 Wcm^{-2}. Outer surface is assumed to have an insulated boundary condition.The temperature of the support and the blood sample is taken as 275 K at t=0 s.Support thickness of 15 mm is selected as an optimum thickness by the support thickness analysis which is carried out to study microwave power absorption within blood samples with various supports combination.

2. RESULT AND DISCUSSIONS

The introductory study has been carried out to obtain the average power as a function of sample thickness via average power vs sample thickness diagram and the data obtain is plotted as in Fig.2 and Fig.3. Two consecutive resonances termed as R1 and R2 modes are observed for the specific sample thickness signifying the maxima in average power. Constructive interference between the transmitted and the reflected wave cause this significant resonances R1 and R2. This preliminary study is used for determining the specific sample thickness (L_s) corresponding to the resonances R1 and R2 for the further processing of the blood samples at 915 MHz and 2450 MHz.

Fig.2 shows the lucid illustration of the average power description as a function of the sample thickness for the blood samples placed on Teflon, Alumina, Sic and metallic plates. It is observed from the figure 2 and figure 3 that the average power corresponding to R1 mode is greater than that of R2 mode.

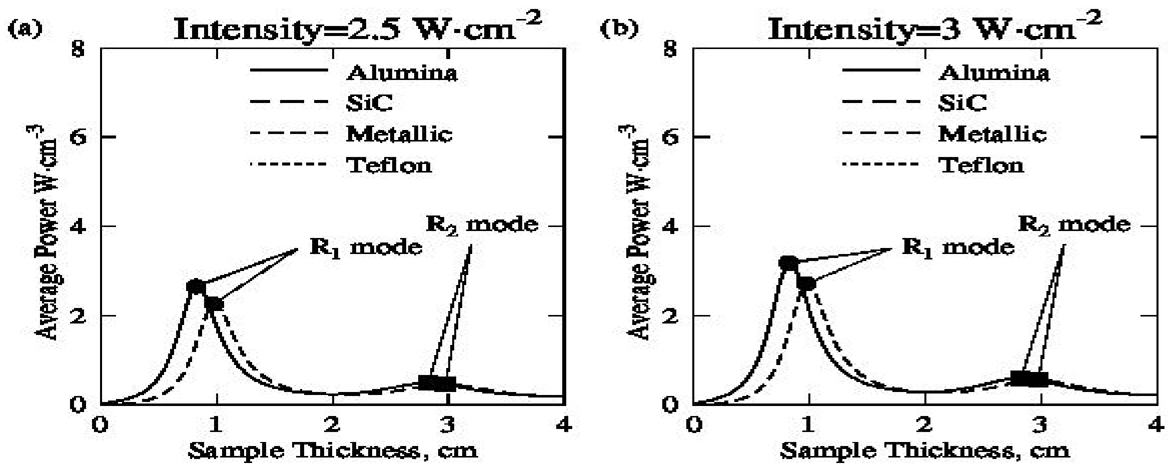

Figure.2: Plot for Average Power vs. Sample Thickness at 915 MHz MW frequency.

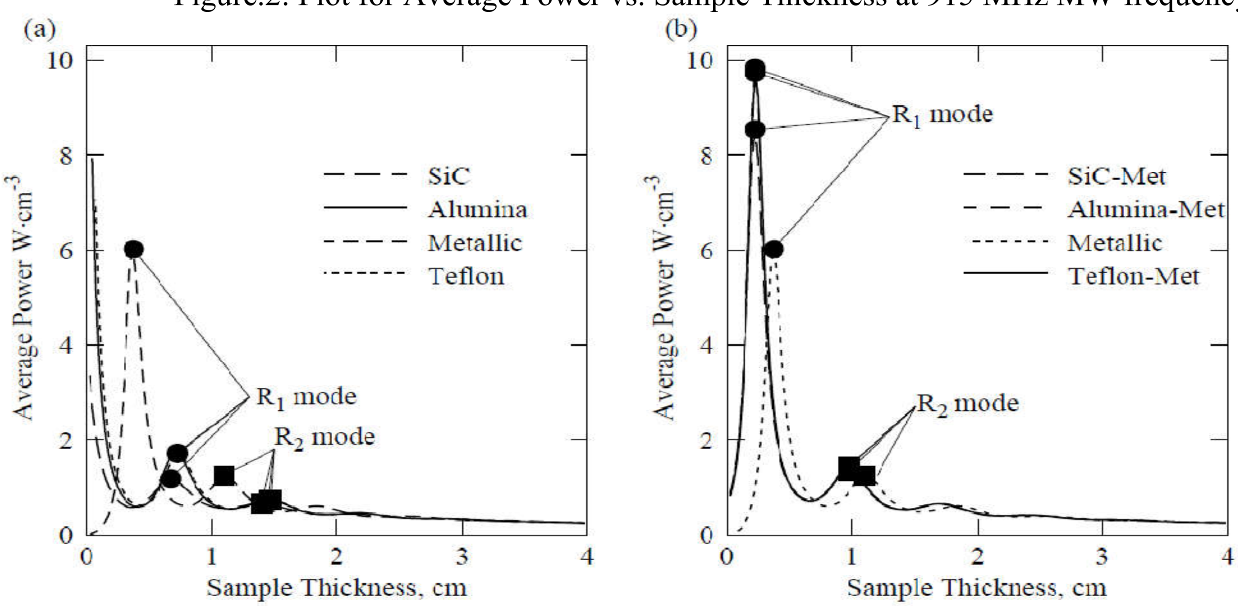

Figure.3: Plot for Average Power vs. Sample Thickness at 2450 MHz MW frequency.

It may also be noted that the microwave power absorption is greater when the blood sample is placed in the metallic and composite supports (Teflon-metallic, Alumina-metallic and SiC-metallic supports) for both resonance mode R1 and R2. It may also be noted that the average power for samples at the MW frequency of 2450 MHz and intensity 2.5 Wcm^{-2} with SiC, Alumina, Teflon, Metallic, Sic-Metallic, Teflon-metallic, Alumina-Metallic during R1 mode are 1.18, 1.73, 1.70, 6.02, 8.54, 9.74 and 9.85 W/cm^3 respectively with the sample thickness of 0.675, 0.725, 0.725, 0.375, 0.225, 0.225 and 0.225 cm respectively. But at the MW frequency of 915 MHz and intensity Wcm^{-2}, the average power obtained during R1 mode with metallic, Alumina-metallic, SiC-Metallic and Teflon-Metallic support are 2.259, 2.663, 2.634 and 2.662 W/cm^3 respectively with the sample thickness of 0.975, 0.825, 0.825 and 0.825 cm respectively.

The average power for samples at the MW frequency of 2450 MHz and intensity 2.5 Wcm^{-2} with SiC, Alumina, Teflon, Metallic, SiC-Metallic, Teflon-metallic, Alumina-Metallic during R2 mode are 0.65, 0.75, 0.73, 1.24, 1.34, 1.44 and 1.44 W/cm3 respectively with the sample thickness of 1.40, 1.45, 1.48, 1.10, 0.98, 0.98 and 0.98 cm respectively. But at the MW frequency of 915 MHz and intensity 2.5 Wcm^{-2}, the average power obtained during R2 mode with metallic, Alumina-metallic, SiC-Metallic and Teflon-Metallic support are 0.465, 0.490, 0.488 and 0.490 W/cm3 respectively with the sample thickness of 2.975, 2.825, 2.825 and 2.825 W/cm3 respectively.

With 2450 MHz MW frequency and 2.5 Wcm^{-2} intensity, the absorption power for sample with metallic support during R1 and R2 mode is larger than with ceramic and teflon support and it will more enhanced with the composite supports.

With 915 MHz MW frequency and 2.5 Wcm^{-2} intensity, the average power for ceramic is quite smaller than with metallic support especially during R1 mode. Blood sample with SiC-Metallic has largest average power of W/cm^3 during R1 mode and Alumina-metallic and Teflon-metallic has the largest average power absorption of 0.490 W/cm^3 during R2 mode.

Spatial distribution of amplitudes of electric fields, power and temperature for blood samples placed on metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic supports during R1 mode is also analyzed. For the microwave frequency of 2450 MHz sample thickness corresponding to R1 mode are 0.375, 0.225, 0.225 and 0.225 cm for samples with metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic supports respectively. For the microwave frequency of 915 MHz sample thickness corresponding to R1 mode are 0.975, 0.825, 0.825 and 08225 cm for samples with metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic supports respectively. The inset plotted shows the difference in phase angles vs. distance within emulsion slabs. The strength of the stationary wave is illustrated by the difference in phase angles and the constructive interference (resonances) is signified by the zero phase difference whereas $\pm\pi$ signifies the destructive interference.

It is observed that the cause of occurring of destructive interference is due to the identical magnitudes of transmitted and reflected waves with π phase differences. So, it causes in absorption of greater power throughout the samples except at the unexposed end.

Temperature vs. slab depth diagram is analyzed for temperature distribution where temperature are taken at t = 10, 20 and 30 s. For 2450 MHz MW frequency, it is observed that Teflon-Metallic support shows the largest temperature distribution and minimum non-uniformity in temperature distribution. Besides that SiC-Metallic support shows lowest temperature distribution while metallic support shows the maximum non-uniformity in temperature distribution at all-time interval.

For 915 MHz MW frequency, it is observed that at 30 sec, the temperature variation for metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic supports are 278.02-304.76 K, 277.38-304.58 K, 278.84-304.93 K and 277.75-304.93 K respectively.

Spatial distributions of amplitudes of electric fields, power and temperature for blood samples placed on metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic Supports during R2 mode is also analyzed for 915 MHz and 2450 MHz MW frequency at 2.5 Wcm^{-2} intensity. For both the cases 2 maxima in spatial power occurs.

For, 915 MHz MW frequency, average power obtained for the metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic supports are 0.465, 0.488, 0.490 and 0.490 Wcm-3 respectively with the sample thickness (L_s) of 2.975, 2.825, 2.825 and 2.825 cm.

Temperature distribution cases are also illustrated at 10, 20 and 30 s. At 30 s, temperature distribution for metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic are 275.47-281.82 K, 275.37-281.80, 275.59-281.83 and 275.42-281.83 K respectively. The temperature difference (T_{blood}) as a function of time distribution for blood samples placed on the taken supports during R2 mode at 2450 MHz and R1 mode at 915 MHz MW frequency is also illustrated in Fig.4 and Fig.5.

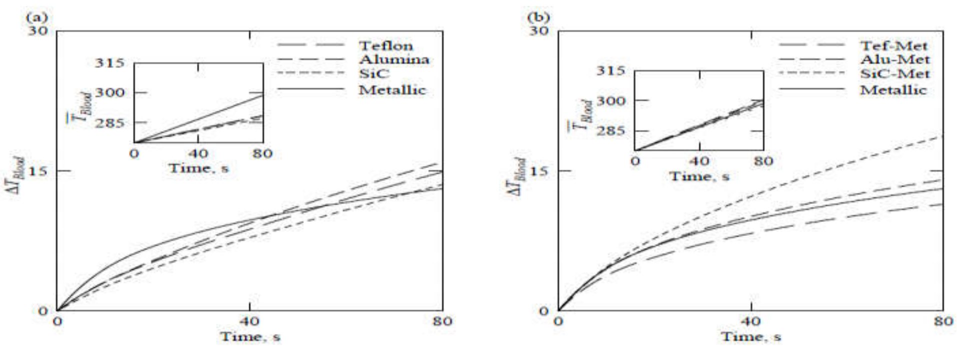

Figure.4: Plot for Average Temperature and Time Difference for different time intervals placed on various supports at 2450 MHz MW frequency.

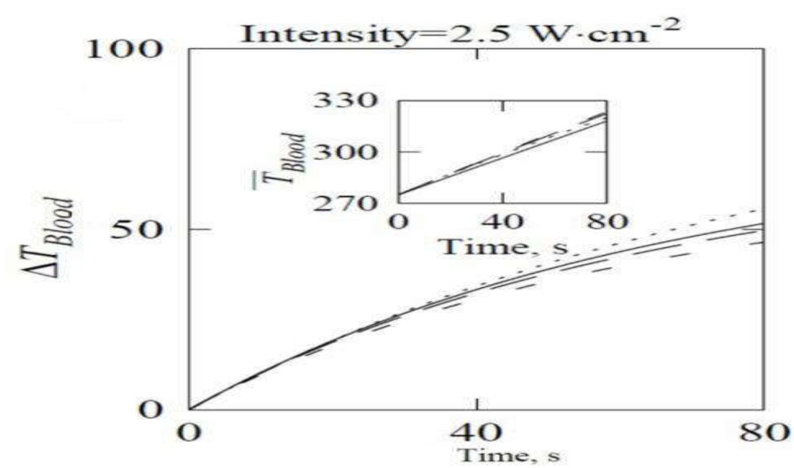

Figure.4: Plot for Average Temperature and Time Difference for different time intervals placed on various supports at 915 MHz MW frequency.

For 2450 MHz, it is observed that during 80 s, temperature difference is found to be relatively smaller for metallic and SiC supports (13.1 k and 13.7 k) whereas it is obtained larger for alumina and teflon supports (15.95 and 14.9 K).

It is found that temperature difference is obtained smallest for Teflon-metallic support (11.4 K) and largest for SiC-Metallic support (18.7 K).

For 915 MHz MW frequency, temperature difference during 80 s (thermal runaway) for metallic, Alumina-Metallic, SiC-metallic and Teflon-Metallic supports are 51.60 K, 49.67, 55.64 and 46.41 K respectively. Hence SiC-metallic is found to have highest thermal runaway and Teflon-Metallic has the smallest thermal runaway. Insets shows the average temperature as the function of time profile where the slope denotes the heating rate which is directly proportional to the power absorption of the microwave. For 2450 MHz, it is observed from the insets that metallic and composite support has larger heating rate of 297.5-300.6 K during 80 s and ceramic/Teflon supports have the smallest heating rates of 287.3-288.6 K. But for 915 MHz MW frequency average temperature for metallic, Alumina-Metallic, SiC-Metallic and Teflon-Metallic supports are 318.06, 322.44, 320.08 and 323.48 K respectively. Here Teflon-Metallic support has largest heating rate and metallic has smallest heating rate.

3. CONCLUSION

A profound analysis has been carried out to study the effect of Microwave heating on blood at the intensities of 2.5 Wcm^{-2} and 3 Wcm^{-2} at two different microwave frequency of 2415 MHz and 915 MHz with the support thickness of 1.5 mm. The comparative analysis of Microwave power absorption is carrried out initially and resonances R1 and R2 is observed and compared. In both the cases (2450 MHz and 915 MHz MW frequency), based on the overall scenarios, it is recommended to choose Teflon-Metallic composite support as the optimal heating strategy for blood samples corresponding to both R1 and R2 modes because of its larger heating rate with minimum non-uniformity in temperature distributions within blood samples and furthermore Microwave frequency of 2450 MHz is recommendable and optimal for the process.

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