CHEMBIOEN-2020 Special Issue

J. Indian Chem. Soc.,
Vol. 97, March 2020, pp. 379-383

1D study on microwave assisted warming of human blood with varied ceramic and composite supports

Sushma Kumari and Sujoy Kumar Samanta*

Department of Chemical and Biochemical Engineering, Indian Institute of Technology Patna, Bihta, Patna-801 106, Bihar, India

E-mail: sksamanta@iitp.ac.in

Manuscript received online 16 December 2019, revised and accepted 06 January 2020

The feature of volumetric processing of the microwave radiation aids in the warming of pre-transfusion human blood to be uniform, controlled, rapid and selective. The 1D study performed to achieve efficient and optimized microwave assisted warming of human blood placed on various ceramic, Teflon and composite supports. The equations for uniform electric field and energy balance are simultaneously solved through the Galerkin finite element method. Preliminary analysis involves studying the amount of average power absorbed by the sample with respect to its thickness for various cases. Moreover, a support thickness sensitivity analysis to recommend a suitable thickness of the support has also been performed. The efficiency of the warming strategy was analyzed based on the observation of higher warming rate and minimum thermal non-uniformity by the procedures. It was observed that corresponding to all the cases and at both the R_1 and R_2 resonances, the metallic and composite supports enhanced the absorption of power. The detailed spatial analysis on the distributions of power and temperature and transient temperature profile provide the recommended combinations for the supports corresponding to both the resonances (R_1 and R_2). The present work acts as a guideline for microwave assisted warming of human blood.

Keywords: Human blood, microwave warming, ceramic/Teflon/composite support.

Introduction

Microwave radiation with the wavelength range of 1 m to 1 mm has various applications in the food, pharmaceutical, ceramic, paper industries, medical field, and many more. During microwave warming, the value of the dielectric loss of the material is responsible for the conversion of the electrical energy into heat energy.

Theoretical analysis on integrated transport of the microwave and thermal energy were introduced by Ayappa *et al.*, in context of the warming of 1D slabs and 2D cylinders[1]. Considerable amount of studies were also devoted on analyzing the effect of resonance due to microwave propagation[2,3]. Barringer *et al.*, and Ayappa *et al.*, found the occurrence of resonance selectively for specified geometries such as 1D slabs or 2D cylinders[2,3]. Some of the investigations observed that microwave warming and transport models together resulted in improved processing of multiphase systems and were inferred to be the effect of resonance[4–6]. Majority of prior studies were solely dedicated to the microwave warming of individual or multilayered samples and only few were about microwave assisted processing of multiphase systems, such as biological samples[7–10]. The microwave assisted warming of intravenous fluids and the thermal effects were investigated by Anshus *et al.*[9].

Warming of the human blood collected at the blood bank prior to the transfusion is a very fundamental and highly important medical practice. The conventional methods of warming of human blood may not to be useful in emergency situations due to long hours taken by the procedures to warm the blood sample. Hence, microwave assisted warming of the human blood could be extremely beneficial especially during the situations of emergency requirement of massive quantity of human blood in very short duration.

The work performed here aims to analyze the effect of varied supports such as Alumina, Teflon, SiC and/or metallic on microwave assisted warming of human blood in the form of 1D slabs. The work presented here gives priority to the condition required for ensuring uniform warming with minimum temperature non-uniformity in the given bulk sample. It has been assumed that the human blood is available at 275 K and the warming is performed till blood sample obtains ambient temperature of about 303 K.

Theory:

Evaluation of electric field and power:

The investigation will be performed on the warming features of human blood placed on varied supports like Teflon, ceramic and/or metallic (Fig. 1). The Maxwell's equation gives information about propagation of electromagnetic wave for an uniform electric field E_x.

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

The electric field lies in the *x-y* plane and changes in only along the *z* axis which is the propagation direction (Fig. 1). The propagation constant (κ) is dependent on dielectric constant (κ'), dielectric loss (κ'') and angular frequency ($\omega = 2\pi f$) and is calculated as $\kappa = \frac{\omega}{c}\sqrt{\kappa' + i\kappa''}$. Here, *f* and *c* are the frequency of the microwave radiation and velocity of light, respectively. In the sample of '*n*' multilayers, the electric field for *l*-th layer is calculated using eq. (1) and given as

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

where $Z_{l-1} \le Z \le Z_l$ and $l = 1 \cdots n$.

The Poynting vector theorem gives the extent of absorption of power in the *l*-th layer as

$$q_l(z) = \frac{1}{2}\omega\varepsilon_0\kappa''_{\text{eff}}E_{x,l}(z)E^*_{x,l}(z) \quad (3)$$

Here, ε_0 is permittivity of free space, and κ''_{eff} is effective dielectric loss.

The average power which is obtained on integrating the power absorbed by each layer through the slab thickness is given as

$$\bar{q} = \frac{1}{2L}\int_{-L}^{+L} q_l(z)dz \approx \frac{1}{2L}\sum_{z=0}^{2L} q_l(z) \quad (4)$$

Here, the integration limits $-L$ and $+L$ is the representation of the extreme ends of the slab at the left and right sides, respectively. $q_l(z)$ is the power calculated as a function of *z. 2L* is assumed as the thickness of the entire slab.

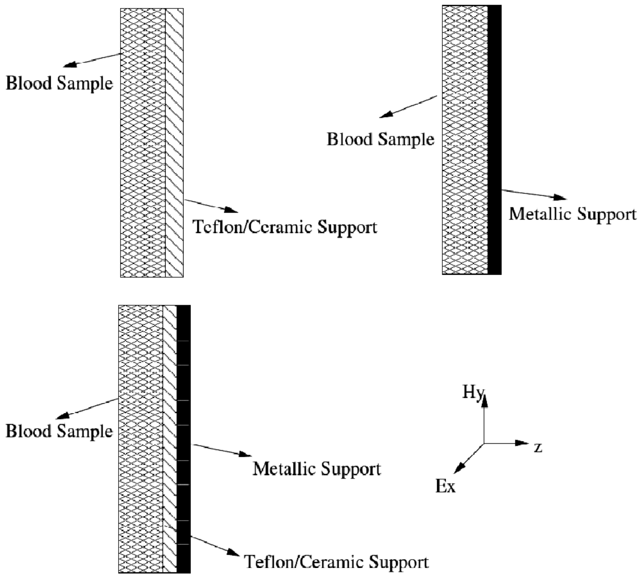

Fig. 1. The schematic representation of a human blood sample placed on Teflon/Ceramic and/or Metallic and composite supports warmed by microwave radiation.

The average power absorption in a sample of thickness L_s is given by

$$q_{av} = \frac{1}{n}\sum_{i=1}^{n} q_l(Z_i), \quad 0 \le Z_i \le L_s \quad (5)$$

The equation for energy balance with heat generation term entirely caused by the interaction of the microwave radiation with the sample is given by

$$\rho c_p \frac{\partial T}{t} = k\frac{\partial^2 T}{z^2} + q(z) \quad (6)$$

where ρ, c_p and *k* represent the values of effective density, specific heat and thermal conductivity, respectively.

Solution strategy:

The dielectric and thermal properties of the human blood and materials used as the support have been drawn from the literature for the computations[6,10]. In each case, the sample is subjected to microwave radiation of frequency 2450 MHz and intensity 2.5 W cm^{-2}. Insulation at the outer surfaces has been assumed as the boundary condition. The temperature of the human blood and the support is assumed as 275 K at $t = 0$ s. Moreover, a support thickness susceptivity study has also been performed to calculate the extent of absorption of power occurring inside the human blood sample with varied supports which gives 0.15 cm as the optimum support thickness.

Results and discussion

The plot representing the extent of absorption of average power for different sample thicknesses has been studied for a preliminary analysis as shown in Fig. 2 with aim to understand the interaction effect between microwave radiation and human blood. The peaks observed in the average power at specified sample thicknesses were termed as resonances. We observe that two such resonances were obtained and labeled as R_1 and R_2. The occurrence of the resonances can be attributed to the constructive interferences taking place between transmitted and reflected waves.

Figs. 2a-b demonstrate the distribution of average power with respect to sample thickness of the human blood supported by Alumina, SiC, Teflon and/or metal. It is observed that the average power absorption corresponding to R_1 resonance is higher than that to R_2 resonance for all the combinations of the support. It is noticed that the average power absorbed by the human blood when provided with metallic support at both the R_1 and R_2 resonances is greater than that for human blood with Alumina, SiC or Teflon supports. It is noted that the absorption of power enhances significantly in the case of composite supports (Teflon-metal, Alumina-metal and SiC-metal) than that compared to the cases of metallic or Teflon/ceramic supports for both the resonances. It is observed that, the human blood supported by composites of Teflon-metal and Alumina-metal result in the highest average power absorption whereas blood supported by SiC causes the lowest average power absorption at both the R_1 and R_2 resonances.

The most appropriate selection of the supports, either single or composite is influenced by the parameters such as the processing thickness, rate of warming and thermal non-uniformity. The important factors observed from the plot of average power with respect to the thickness of the sample lay an appropriate guideline for the determination of the efficient warming strategy of the human blood when supported by varied single/composite supports through microwave radiation (Fig. 2a-b). The subsequent detailed study performed next on the characteristics of the microwave power and the distribution of the electric field at the selected resonances aids in the understanding of the importance of the selected supports for achieving an optimal processing of the human blood.

Fig. 3 demonstrate the spatial distribution of the amplitude of electric fields, the power and the temperature of the human blood supported on metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic surface at the R_1 resonance. The insets inside the figure represent the difference in the phase

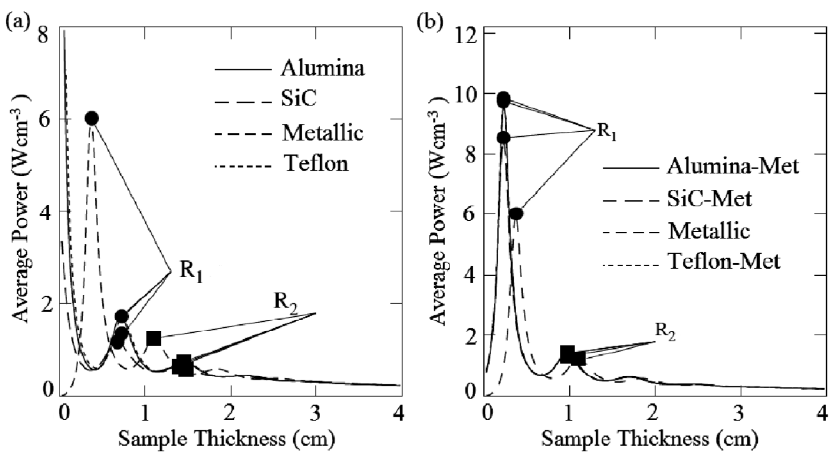

Fig. 2. The schematic representation of average power with respect to sample thickness during microwave assisted warming of human blood placed on (a) Alumina, Sic, Metallic and Teflon supports and (b) Alumina-Met, Sic-Met, Metallic and Teflon-Met composite supports.

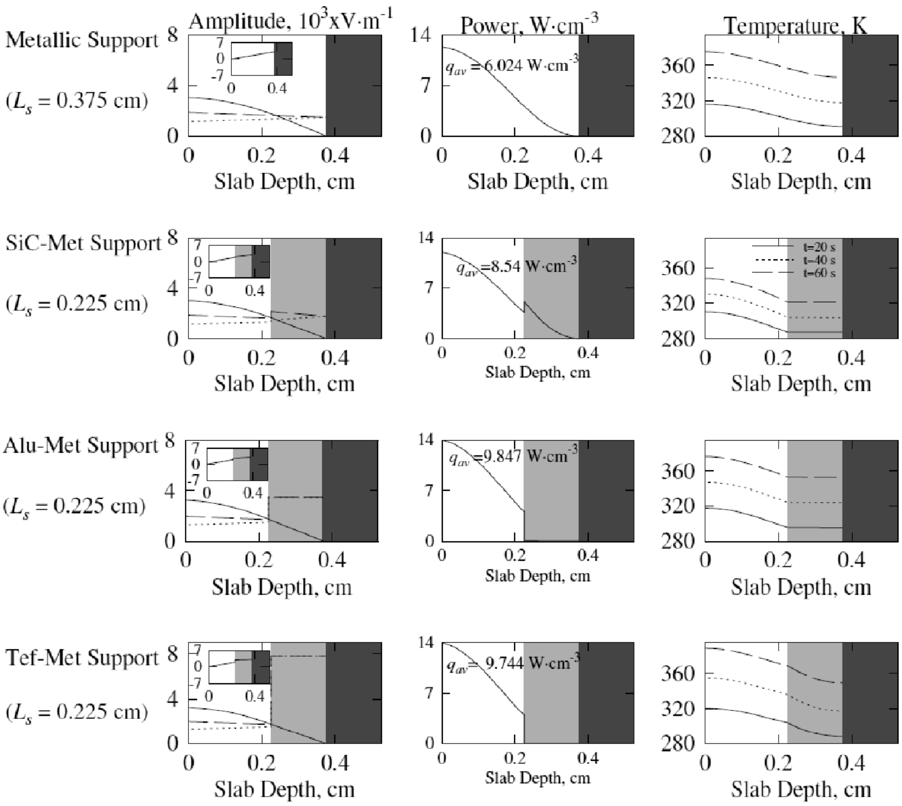

Fig. 3. The schematic representation of spatial distributions of electrical field amplitude, power and temperature during microwave assisted warming of human blood placed on Metallic, SiC-Metallic, Alumina-Metallic and Teflon-Metallic supports at R_1 resonance. – – Transmitted wave; · · · Reflected wave; — Stationary wave.

angles with respect to the distance within the composite slabs. It has been observed that destructive interferences occur due to the comparable magnitudes of the transmitted and reflected waves with the phase difference of π on the surface of the metallic support. Hence, higher absorption of power throughout the blood sample occurs with the exception of the unexposed end. The situation is observed to exhibit improvement when the composite supports are included. This inclusion aids in the occurrence of non-zero spatial power on the interface of the human blood and the support resulting in higher absorption of power.

The distribution of temperature through the plot of spatial temperature vs slab depth has been observed at different time durations i.e. 20, 40 and 60 s (Fig. 3). The composite support of Teflon-metal is detected to exhibit highest temperature distribution whereas the support SiC-metal exhibits the lowest temperature distributions during all the time intervals. The composite support of Teflon-metal exhibits the highest thermal uniformity in contrast to the metallic support which shows the lowest thermal uniformity at all the time intervals.

Fig. 4a-b demonstrates the temperature difference (ΔT_{Blood}) with respect to time for the human blood placed on (a) Metallic, Teflon, Alumina and SiC supports and (b) Metallic, Teflon-Metallic, Alumina-Metallic and SiC-Metallic supports at R_2 resonance. The ΔT_{Blood} represents the difference between the highest and lowest temperature inside the sample and is observed to be relatively lower for metallic and SiC supports and relatively higher for Alumina and Teflon supports (Fig. 4a). It is also observed that, temperature difference is lowest for Teflon-metallic supports and highest for SiC-metallic supports (Fig. 4b).

The insets in Fig. 4 exhibit the value of average temperature ($\bar{T}_{\text{Blood}}$) against time which denotes the warming rate. The occurrence of higher warming rates and minimum ther-

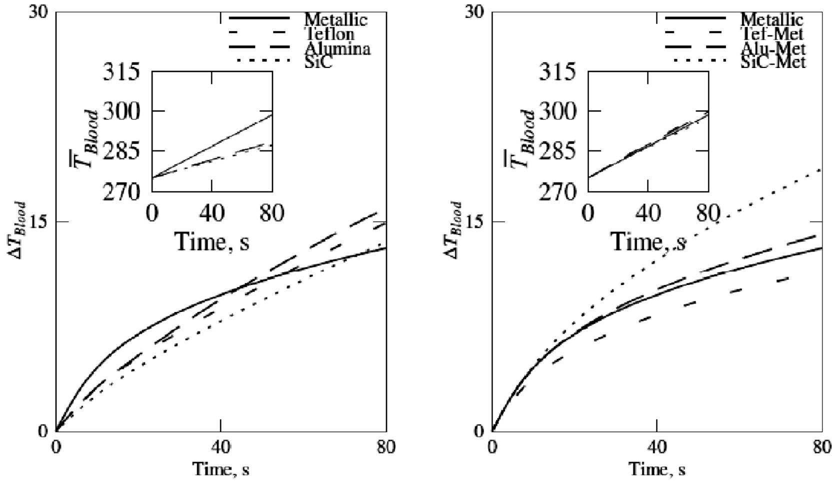

Fig. 4. The schematic representation of average temperature and temperature difference with respect to time during microwave assisted warming of human blood placed on (a) Teflon, Alumina, SiC, Metallic supports and (b) Teflon-Metallic, Alumina-Metallic, SiC-Metallic, Metallic supports at R_2 resonance.

mal non-uniformity during the warming of the human blood is assigned as the most optimum heating strategy. It is observed that the human blood with metallic and composite supports correspond to higher warming rates than that with ceramic/Teflon supports (Fig. 4a-b). Observing all the case studies, the Teflon-Metallic composite can be assigned as the best support which results in the most optimum warming strategy for human blood corresponding to both the R_1 and R_2 resonances.

Conclusions

Extensive analysis have been performed to investigate the effect of Teflon, Ceramics (SiC, Alumina) and/or Metallic supports on microwave assisted warming of human blood. A preliminary study on the absorption of power has been performed with respect to the sample thickness. The absorption of microwave power is observed to be enhanced significantly with the aid of metallic and composite supports (Teflon-Metallic, Alumina-Metallic and SiC-Metallic supports). The efficient warming strategies categorized by the higher warming rates with minimal thermal non-uniformity within the sample have been analyzed for both small samples (R_1 resonance) and large samples (R_2 resonance). This observation is based on the observations made from the plots of the distribution spatial power and temperature along with the transient temperature profile. Overall, Teflon-Metallic composite support has been observed to exhibit the most optimum warming strategy during the 1D microwave assisted warming of the human blood corresponding to both the R_1 and R_2 resonances.

References

1. K. G. Ayappa, H. T. Davis, G. Crapiste *et al., Chem. Engg. Sci.*, 1991, **46**, 1005.
2. K. G. Ayappa, H. T. Davis, S. A. Barringer *et al, AIChE J.*, 1997, **43**, 615.
3. S. A. Barringer, E. A. Davis, J. Gordon *et al., J. Food Sci.*, 1995, **60**, 1137.
4. T. Basak and K. G. Ayappa, *AIChE J.*, 1992, **43**, 1662.
5. S. K. Samanta, T. Basak and B. Sengupta, *Int. J. Heat Mass Transfer*, 2008, **51**, 6136.
6. T. Basak and A. S. Priya, *Chem. Engg. Sci.*, 2005, **60**, 2661.
7. S. C. Kashyap and G. Rock, IEEE, Microwave Conference, 12th European, 1982, pp. 405-407.
8. N. L. Campbell and J. Drewe, IEEE MTTS International, 1981, pp. 479-481.
9. J. S. Anshus, G. L. Endahl and J. L. Mottley, *Am. J. Emerg. Med.*, 1985, **3**, 316.
10. T. Wessapan, S. Srisawatdhisukul and P. Rattanadecho, *Int. Commun. Heat Mass*, 2011, **38**, 255.