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A New Approach of Localized Human Blood Reheating using High Frequency Converter

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Abstract

The paper presents the human blood reheating technique for medical purposes with high frequency induction heating system. The temperature is analyzed to determine the heat distribution in different positions of human blood within the non metallic tank. In the proposed induction heating system, the inductive applicator is a primary working coil of the modified half bridge high frequency inverter and the RBCs within the blood will be working as secondary element. The simulation shows that the heating area can be effectively controlled by using the cylindrical shield with adjustable space. However, the efficiency of heat can be increased by varying the radius size of cylinder thereby more flux appears and more eddy emf is induced. Hence the resulting eddy current increases the refrigerated blood of range 1ºC- 6ºC to 37ºC.

Keywords: *blood reheating, blood transfusion, modified half bridge inverter, induction heating, COMSOL*

1. Introduction

The general purpose of a heat treatment is to enhance blood flow rate before transfusion [1]. Basically superficial and deep heat treatment processes are used in medical system for blood warming. Superficial heat treatment introduces heat to the body surface while the deep heat treatments direct heat toward specific inner tissues through ultrasound technology and by electric current [2-9].

The hydrotherapy heat treatment is used for many musculoskeletal disorders. Fluidic therapy is a form of heat treatment, are basically used in medical treatment purposes [12].

Among the three basic heat transfer methods the radiation technique involves the transmission and absorption of electromagnetic waves to produce a heating effect [24-25].

2. Blood Composition

The red blood corpuscles (RBCs) contain hemoglobin molecule which is an assembly of four globular protein subunits. Each subunit is composed of a protein chain tightly associated with a non-protein heme group [10-12].

The iron ion (heme) may be either in the Fe^{2+} or in the Fe^{3+} state [13]. These Fe^{3+} ions exhibit the magnetic property [6]. Hence in the proposed technique the heating element of blood i.e. RBCs themselves will work as a secondary element. Thereby eddy emf will be generated and blood will be heated as per requirement. In high frequency induction heating the blood composition remains unchanged [14-16].

3. Methods and Discussion

Induction heating involves applying an ac electric signal to a coil placed near specific place in the heating loop and the metallic object will be heated [16]. The alternating current creates an alternating magnetic flux within the metal to be heated in the loop. Eddy emf is

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induced in the metal by the electromagnetic flux and heats up the material [18]. Fundamental theory of induction heating is similar as transformer operation, where primary coil is treated as heating coils and the current induced in secondary is directly proportional to primary current according to turn ratio [19]. Figure 1 shows the equivalent circuit of transformer. When the secondary is single turned and short circuited shown in Figure 2 then a substantial heat loss occurs due to increased secondary load current. Here, Z_L is the path resistance of blood flow.

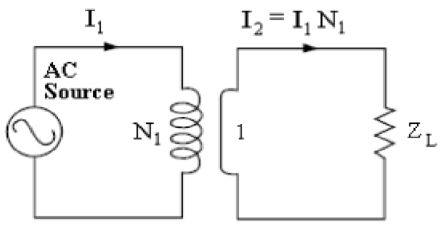

Figure 1. Equivalent circuit of transformer

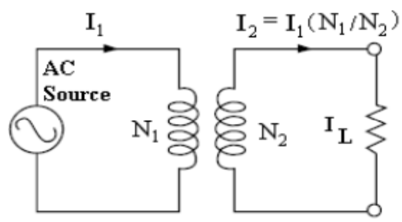

Figure 2. Single turned and short circuited Secondary

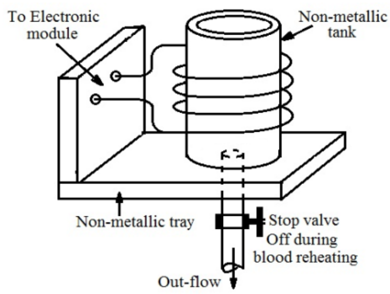

Figure 3. Diagram of blood heating through non-metallic tank

Figure 3 shows a system where the blood supplied from the source is of the same amount as the combined loss of the primary and secondary. Here blood is considered the secondary element of the heating element. When blood will be cut by the flux then eddy emf will be developed in the blood so the blood will be heated [19-20].

Basically eddy current has most important role for heating of blood. Whereas, for magnetic material there will be some contribution from hysteresis loss. This loss (hysteresis Power) is proportional to frequency (f) and the eddy current loss (eddy Power*)* is proportional to square of frequency (f^2) for magnetic material.

$$P_{Hys} = K_h f \; B_{max}^{1.6}$$

$$P_{Eddy} = K_e f^2 B_{max}^2 \tag{1}$$

Where, K_h, K_e and B_{max} are constants of hysteresis loss, eddy current loss and maximum flux density, respectively.

Therefore, hysteresis loss becomes small compared to the eddy current loss at higher frequency. On the other hand, depth of saturation is inversely proportional to frequency. Hence, selection of a proper value of the frequency is required.

$$\delta = \sqrt{\frac{\rho}{\pi \mu f}} \tag{2}$$

Where, ρ = specific resistance of the work-piece and μ= permeability of the work piece.

Figure 5 indicates a specially designed eddy current heated static blood package developed in the proposed scheme which is tightly incorporated into the non-metallic vessel or tank in the tank [21].

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2, 5]. The discussion can be made in several sub-chapters.

4. Advantages of New Practice over Prior Scheme

Prior to the development of induction heating, microwave provided the prime means of heating human blood. Induction heating offers a number of advantages over that heating:

Quick heating: More quick response rates than the convection, radiation and dielectric processes.

Heat distribution: More uniform heat distribution than other heating processes.

Temperature control: Smooth and easy temperature control is possible with high frequency heating.

Reliability: Good compactness and high reliability in high frequency heating.

Energy savings: High energy density can be achieved by producing sufficient heat energy with a relatively small period of time. But with the other processes energy must be supplied continuously to maintain temperature during processing as a result time delaying.

Moreover the high frequency induction heating provides other advantages such as easy of automation and control, Requirement of less maintenance, safe and clean working conditions [21].

5. Proposed Modified Half Bridge Inverter for Blood Reheating

In the circuit operation has been discussed in detail. Here human blood is considered secondary coil of heating element which can be passes through the vessel or placed in the vessel thereby it can be reheated with this proposed inverter [22]. The exact circuit diagram of the Modified Half Bridge inverter is shown in Figure 4.

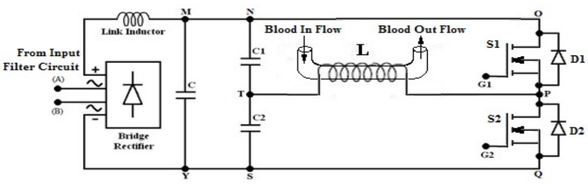

Figure 4. Proposed circuit diagram of modified half-bridge inverter

Table 1. Switching ON-OFF chart of MOSFETs (BF1207)

S1	S2	V_{out}
ON	OFF	$+V_i/2$
OFF	ON	$-V_i/2$

Modified half bridge circuit is normally used for higher power output. Four solid state switches are used and two switches are triggered simultaneously. Here MOSFETs (BF1207) are used as solid state switches because it can be exist at high frequency applications. Anti-parallel diodes D1 and D2 are connected with the switches S1 and S2 respectively that allows the current to flow when the main switch is turned OFF. The operation of solid state switches can be depicted as shown in Table 1. According to Figure 7, when there is no signal at S1 and S2, capacitors C1 and C2 are charged to a voltage of Vi /2 each. The Gate pulse appears at the gate G1 to turn S1 ON. Capacitor C1 discharges through the path NOPTN. At the same time capacitor C2 charges through the path MNOPTSYM. The discharging current of C1 and the charging current of C2 simultaneously flow from P to T. In the next slit of the gate pulse, S1 and S2 remain OFF and the capacitors charge to a voltage Vi /2 each again. The Gate pulse appears at the gate G2, so turning on S2. The capacitor C2 discharges through the path TPQST and the charging path for capacitor C1 is MNTPQSYM. The discharging current of C2 and the charging current of C1 simultaneously flow from T to P. The both switches must operate alternatively otherwise there may be a chance of short circuiting. In case of resistive load, the current waveform follows the voltage waveform but not in case of reactive load. The feedback diode operates for the reactive load when the voltage and current are of opposite polarities [26-27].

6. Simulation Results and Discussion

In this context Figure 5 depicts that the surface temperature distribution by the proposed technique for blood reheating before transfusion to human body. The average temperature of the blood through non-metallic tank has increased with in small period of time due to increasing eddy emf. The temperature field follows the heat-source distribution quite well. That is, near the protrusion the heat source is strong, which leads to high temperatures and the blood manages to keep the tissue at normal body temperature without damaging the blood particles.

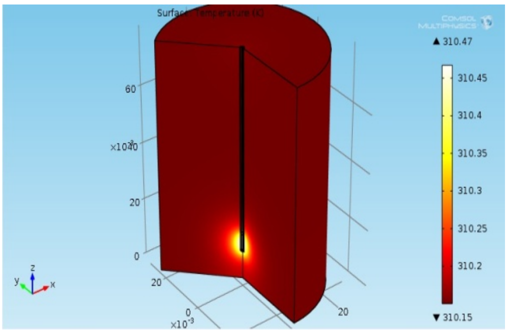

Figure 5. Surface Temperature distribution in the blood cell in K

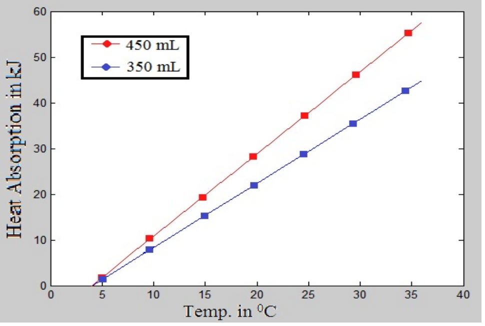

Figure 6. Heat absorption of blood for different mass in kJ

Figure 6 shows the resulting heat absorption of different mass at steady-state temperature distribution in the human blood. The amount of heat required to raise the optimal temperature is 46.2kJ and 59.4 kJ for 350 mL and 450 mL blood tank respectively.

Figure 7 and Figure 8 show the induced eddy voltage and eddy current in the blood tank by Modified Half Bridge inverter fitted induction heater respectively. The rms output voltage is 108.2 volt across T and P point of Figure 5. The rms output current is 9.46 ampere through blood tank, which are taken in the platform of PSIM. The analysis revels that with this scheme 350 mL and 450 mL of blood could reach its optimal temperature within 45s and 58s respectively.

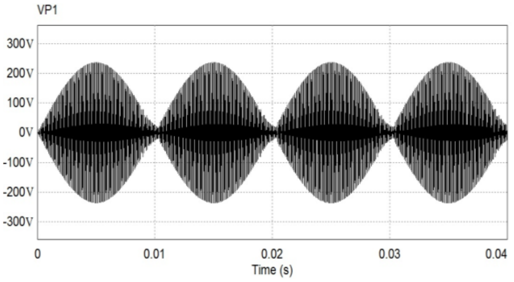

Figure 7. Induced Eddy voltage in the blood tank

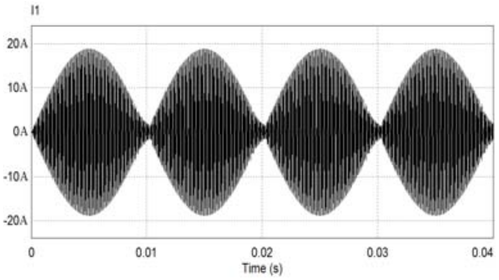

Figure 8. Eddy current in the blood tank

Figure 9 plots the specific absorption rate (SAR) along a line parallel to the receiver. From the above graph it can be predict that this inverter good for conformity of blood reheating and results clean heat production for human blood reheating which is required before blood transfusion to human body.

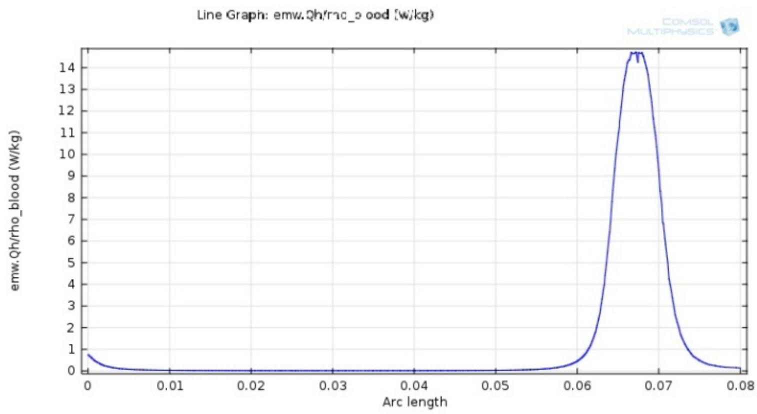

Figure 9. Graph of specific absorption rate in W/Kg Vs arc length

The eddy currents in a conductive cylinder produce heat. Here, the ohmic losses and temperature distribute in the vessel, the heat transfer and electric field simulations must be carried out simultaneously.

From the above results it can be predict that proposed modified half bridge inverter will give new setup in medical sciences for quick blood reheating before transfusion to human body.

7. Conclusion

Hence apart from other types of heat exchangers used in medical science, this proposed technique with high frequency induction heating will be more suitable as it follows the protocol for fast blood heating without damaging blood composition due to excessive heat. However this modified half bridge inverter may be used in medical sciences for localized blood reheating before transfusion to human body.

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