Design of A System for Determining the Temperature in the Presence of Magnetic Fluids a Magnetic Field

Fatima Moumtadi* and Pavel Adolfo Figueroa Rodriguez

*Corresponding author email id: fatimoun@hotmail.com

Abstract – The temperature increase curve is useful for the characterization of magnetic fluids which are used as a source of hyperthermia for cancer treatment or drug delivery. The present work was designed and implemented an electronic temperature measurement with an infrared sensor, a thermocouple and type sensor zener for magnetic fluids in the presence of an alternating magnetic field. The curve of temperature increase versus time was obtained. With the temperature curve and changing the concentration of nanoparticles fluid, curve specific absorption coefficient $C_S$ in function of the concentration of $\rho$ nanoparticles was obtained.

Keywords – Infrared Sensor, Semiconductor Sensor, Thermocouple, Magnetic Fluid.

I. INTRODUCTION

Over recent years it has investigated the use of magnetic fluids (fluids composed of magnetic nanoparticles whose mutual interaction is negligible) as a form of targeted thermotherapy [1, 2, 3]. Combining the use of magnetic nanoparticles (which are particles with magnetic properties whose dimensions are in the range of 1 [nm] and 100 [nm]) with transport systems of drugs whose release can be controlled with temperature [4, 5, 6], may provide further treatment is made.

Magnetic fluids are investigated for use in diagnosis and treatment [8]. In investigated diagnostic as contrast agents in images [9]. Magnetic fluids, are also used in magnetic resonance imaging (MRI) [10, 11]. They can also be used as transport system drugs and as a source of hyperthermia (hyperthermia is to raise the temperature above 41 °C [13] in a region of the human body) because their nanoparticles increase their temperature before the influence of external magnetic fields.

Hyperthermia in oncology always goes hand in hand with some other therapy. Hyperthermia is also a way of sensitizing cells that have developed resistance to conventional treatments so can be used in improving cancer therapy [14, 15]. One of the difficulties is to reach the region where it can perform any type of applicator, being more difficult in deep body sites.

Some systems that could meet the transportation system as a source of drugs and hyperthermia are magnetoliposomes [14, 15, 16, 17, 18, 19, 20].

The liposomes are magnetoliposomes inside carry a charge of magnetic nanoparticles. In general, liposomes are spherical vesicles made from phospholipids [24], which generally consist of two fatty acids (hydrophobic) attached to a phosphate (hydrophilic) and these in turn linked by a glycerol molecule. Liposomes have been used as carriers of various components, such as drugs or proteins [25].

Use of magnetic nanoparticles into liposomes is intended to release the load by increasing temperature, the temperature increase changes the permeability of the membrane releasing more of its content, if the temperature exceeds the transition point phase structure liposome is lost and the content is released, if the load is sufficient nanoparticles can also be used for this hyperthermia therapy in the region of interest thus achieving a dual purpose: depositing a drug and applying hyperthermia in only one region. This has the advantage of using a smaller amount of drug, reduce side effects in patients and not damage healthy tissues.

To assess the response of a magnetic field to an alternating magnetic fluid they have been developed and improvised various devices; those facts to determine the Specific Absorption Rate (SAR).

In the use of magnetic fluids for hyperthermia the term Specific Absorption Rate (SAR), in [21], it is defined as the power dissipated [22] per unit mass for a field and frequency. The SAR provides information on the heat transfer in a magnetic fluid, or the heating efficiency [23]. For magnetic fluids usualy assessed by subjecting the fluid to an alternating magnetic field, determined maximum amplitude and frequency while the temperature rise is measured. The magnetic field is generated with an electric current flowing in a coil, the fluid to be analyzed is placed in the center.

The temperature measurement in tests hyperthermia with magnetic fluid is carried out in various ways. In [3] is performed with an infrared camera, this method however does not disclose the temperature within the fluid. In [7] an infrared thermometer is used. In [12] an analysis was made using temperature measurements adiabatic and not adiabatic, using thermocouple and fiber optic thermometer.

In this paper the temperature measurement in the magnetic fluid is focused on the evaluation of a thermocouple, an infrared sensor and a sensor zener type. The first is a device consisting binding of two different metals [26] its operation is based on the formation of a voltage when the end of a conductor is heated [27]. The thermocouple has a nonlinear response, due to the contribution of a non-reversible effect (Joule effect). The second consists basically of a photodiode in reverse, with a filter that allows only the passage of radiation in the infrared band, the photodiode is coupled to a transimpedance amplifier. The temperature calculation is performed in a microcontroller or DSP (digital signal processor). By last, the third is a semiconductor sensor whose conduction depends on the temperature, at 0 °K it acts as an insulator and as soon as the temperature is higher the conduction begins until the saturation, adding impurities (doping) and making different arrangements between semiconductors (such as NP or PN junctions) allows controlling the conductivity of the material with a potential difference.
II. METHODOLOGY

A. Analysis of the Conditions in which the Measurement is Made

Testing temperature increase nanoparticles made in a unit of hyperthermia.

![Fig. 1. Unit hyperthermia. (A) magnetic fluid container (B) working coil (C) antifreeze circulation tubes (D) Capacitors (E) Current cables.](image)

The frequency at which varies the magnetic field is obtained from a function generator, it passes a signal conditioner generates two square signals reverse with respect to each other, with cycle working close to 50%, subsequently it passes a full bridge MOSFET circuit.

Figure 2 shows the schematic diagram of the stage where the work coil \( L_1 \) is the ratio of inductances \( T_1 \) is the unit and serves as choke coil, terminals A and B are connected directly to the bridge transistors.

![Fig. 2. Diagram of electric stage where the work coil is.](image)

Figure 3 shows the schematic diagram of the stage which handles the transistors, in the signal called "Sign" it is displayed will have the signal from the function generator, the output signal conditioned is disabled with "SW1" earthed and thus the output transistors.

![Fig. 3. Driver and H-Bridge.](image)

To test for temperature increase in the magnetic fluid, the unit is powered at all stages except the H-bridge, the water circulation is started in the work coil, the frequency at which desired work is fixed, the sample is introduced into the work coil and when required starting exposure to field can power the H-bridge and enable the driver MOSFET.

Once the bridge H output is enabled, the magnetic fluid is in the presence of the magnetic field, and this increases its temperature after a certain time, so that the increase responds to the following model:

\[
\frac{dT}{dt} = C_S - K_m T(t)
\]

where \( C_S \) is the specific absorption coefficient, \( K_m \) the heat in the room at constant temperature, with:

\[
T(t) = T_n(t) - T_m
\]

where \( T_n \) is the temperature of the magnetic fluid and \( T_m \) constant temperature of the medium in which it is immersed.

B. Analysis of the Measurement Method

In order to obtain \( C_S \) to obtain the SAR (Specific Absorption Rate) depending on the concentration of certain magnetic fluid, it is necessary to measure the temperature increase of the fluid, this increment, if \( T_m = cst. \) if it must be of the form:

\[
\Delta T(t) = a - be^{-ct}
\]

with a ≈ b, it can be said that \( C_S \) it is:

\[
C_S = ac \text{ or } C_S = bc
\]

When analyzing curves \( \Delta T(t) \) at different concentrations, \( \rho_1 \), the curve \( C_S(\rho_1) \) would be of the form:

\[
C_S(\rho_1) = a - be^{-c\rho_1}
\]

Temperature readings thermocouple or infrared or other origin containing metal or semiconductor parts can not be performed in the presence of the magnetic field due to heating suffering, measured by either of these sensors means no magnetic field, and that during measurement the chilled sample, as follows:

\[
\frac{dT}{dt} = K_m \Delta T(t)
\]

Therefore, the temperature drop during measurement is:

\[
\Delta T(t) = \Delta T(t_1)e^{-k_m(t-t_1)}
\]

\[
\Delta T(t) = \begin{cases} 
\frac{C_S}{K_m}(1 - e^{K_m t}) & : [t_0, t_1] \\
\Delta T(t_1)e^{-K_m(t-t_2)} & : [t_1, t_2] \\
\frac{C_S}{K_m}(1 - e^{K_m(t-t_2)}) + \Delta T(t_2) & : [t_2, t_3] \\
\Delta T(t_3)e^{-K_m(t-t_3)} & : [t_3, t_4]
\end{cases}
\]

On the other hand, the \( K_m \) value can determined experimentally, and if conditions are repeated for each...
Sample to be analyzed (same volume, same container and position).

If \( t_f \) is the final time the value of \( C_S \) can be determined as follows:

\[
C_S = \frac{\Delta T(t_f)K_m}{1-e^{-K_m t_f}} \quad (9)
\]

From the above two methods can be proposed for the curve of temperature increase:

1. Taking readings at time intervals following the model of equation 8, adjust to a curve and determine \( C_S \) by Equation 4.
2. Determine experimentally \( K_m \) and determined \( C_S \) by Equation 9.

C. **Design Proposal**

To avoid errors in measurements and that they do not throw us false results, we must keep always constant room temperature, the test should begin when \( T_n = T_m \), the time intervals for exposure and measurement must always be the same, the intervals for measurement must be sufficient to ensure a correct reading, and as short as possible to avoid its impact on growth curve and should reduce personal intervention in the process.

The steps having the process for obtaining the temperature rise curve are proposed as follows, whereas the sample and is within the container are: Enable power H-bridge; Measuring the temperature in the sample and the environment; When \( T_n = T_m \) is removed the temperature probe; Field exposure start enabling the driver H-bridge; Arriving at the time where it should perform temperature measurement, disable driver of the H-bridge; If more measurements are desired, enable H-bridge driver again; At the end the desired measurements, disable power to the H-bridge.

To accomplish the above tasks the system shown in figure 4 is proposed.

![Figure 4](image)

**Fig. 4.** Proposed measuring system. (A) Temperature sensor (B) magnetic fluid container (C) working coil (D) water circulation pipes (E) Motor.

D. **System Design for Temperature Determination**

The overview of proposed system of measurement is illustrated in Figure 5 which shows the architecture of a system to perform all the steps of exposure start and measurement where: K1 enables or disables power to the H-bridge of work coil, K2 enable-disable the driver H-bridge of the work coil, SW0 is a switch for the user initiates the routine exposure, the motor driver positions the probe at one end or the other rail to support sensor. The sensors have their respective stage signal conditioning and communication with the microcontroller. The received data are sent to a computer for processing. In order to optimize response time, a program on the PC is that any routine begins and ends.

![Figure 5](image)

**Fig. 5.** Overview of the measuring system

A banded rail engine controlled by a sensor placed in position for measurement. The motor driver is a module containing a circuit with two H-bridges is connected to the microcontroller to the PWM output for both one direction to the other.

Based on the response obtained from a type K thermocouple, it has the slope is \( m = 40 \mu V/°C \), from this the gain of the amplifier stage to the input of the thermocouple is determined, considering the characteristics of the analog-digital converter used and the help of a polynomial temperature is obtained in the thermocouple tip.

The probe design infrared sensor has an integrated circuit having an infrared temperature sensor for measurements that do not require contact [28], has two ways of communicating the temperature reading, one is by PWM output, and other by communication \( I^2C \).

The semiconductor sensor was connected directly to the controller card, the integrated circuit has three pins two of which power, another is the output, the output voltage is proportional to the temperature 10 [mV/°C].

E. **Implementation**

Figure 6 shows the diagram of the implementation of the measurement system and its link to the rest of the devices on the hyperthermia equipment, a development platform Tiva C brand Texas Instruments was selected for measurement of temperature, and communicate with the rest of the circuits. Chose a program done in Python to coordinate all the tasks you must perform both the measurement system as hyperthermia system, a series of commands sent to the card development they will start at a certain routine, each command only performs a single homework.

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The commands for receiving data and presenting the information were implemented in Python. In the microcontroller system responds to certain commands sent from a PC, the state machine full system is implemented in Python, with the microcontroller element sends a response was implemented, this is so that any changes to the set of tasks no need to program the microcontroller.

Obtaining setting temperature curves obtained by nonlinear least squares method, which considers that has a data set m is the temperature readings of each test, and a function f in this case is the temperature rise curve $\Delta T(t) = a - be^{ct}$. This method seeks to:

$$S(\beta) = \sum_{i=1}^{m} [y_i - f(x_i, \beta)]^2 \quad (14)$$

minimal, to achieve this the Levenberg-Marquardt, an iterative algorithm is used to find the local minimum.

### III. TEST AND RESULTS

The tests performed on the temperature measurement system are reported, with corresponding sensors on a magnetic fluid consisting of cobalt ferrite nanoparticles 10 [nm] in water, with oleic acid as surfactant are reported. In Figure 7 samples at different concentrations magnetic fluid with which tests were performed measuring temperature are observed.

**Fig. 7. Samples magnetic fluid.**

A. **Internal Sensor Test.**

Reading per second is performed and then the information is displayed in a graph. It is implemented as a communication test and displaying data, the test result of ten readings per second is shown in Figure 8.

**Fig. 8. Graph of the output of a test internal sensor.**

B. **Procedure in Magnetic Fluids.**

Five concentrations of cobalt ferrite nanoparticles, 0.2, 0.5, 1.0, 3.0 and 6.0 mg / ml were prepared

Each nanoparticle concentration was exposed to the field for a period of 28 minutes by measuring temperature every 2 minutes, with a total of 14 samples. 4 trials were performed for each concentration, the average of the four readings for the same time measurement was taken. Then an adjustment was made for each of the curves of temperature increase.

From the values is obtained $C_S$ for each concentration, for all measurements are expected value $K_m$ is the same or very similar.

C. **Analysis of Results.**

In the adjustments made for each measurement to each sensor obtained a value of $K_m$, the values they are listed in Table I, and it is noted that these values are very close, expected result since $K_m$ only depends on the medium and not of the concentration.

**Table I. Results of Km for each sensor in different settings.**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Thermocouple</th>
<th>Infrared</th>
<th>Zenner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.10809611</td>
<td>0.10602005</td>
<td>0.112717321</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.00297525</td>
<td>0.00255924</td>
<td>0.00323273</td>
</tr>
</tbody>
</table>

Table II shows the average $K_m$ for each sensor and its standard deviation for the five curves of each concentration is presented.

**Table II. $K_m$ average and standard deviation for each.**

<table>
<thead>
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</table>

Regarding adjustment for obtaining specific absorption coefficient no significant difference between the three sensors used especially between thermocouple and infrared as shown in Table III.

**Table III: Factors to curve specific absorption coefficient against concentration $p_C$.**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Thermocouple</th>
<th>Infrared</th>
<th>Zenner</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>1.19503747583518714</td>
<td>1.224061383337182</td>
<td>1.1760367649937418</td>
</tr>
<tr>
<td>$b$</td>
<td>0.1074359843541587</td>
<td>1.0982017978714523</td>
<td>0.0604006723518692</td>
</tr>
<tr>
<td>$c$</td>
<td>0.1865395630989399</td>
<td>0.1708255969867915</td>
<td>0.201803138986865</td>
</tr>
</tbody>
</table>
IV. CONCLUSION

There was no significant difference between the sensors used in each case. The constant of the medium was very similar for the thermocouple \( K_m = 0.10809611 \) and the infrared sensor \( K_m = 0.10602005 \), the semiconductor sensor differs respect \( K_m = 0.112717321 \), however the standard deviation when compared the difference is not significant. The change in the value of \( K_m \) the last sensor is due to its volume, which suggests that the use of a smaller sensor performs better temperature measurement, or that sensor that does not require contact. Of the infrared sensor and Accordingly thermocouple would be ideal, however, the comparative standard deviation value \( K_m = 0.00297525 \) 0.00255924 thermocouple and for infrared, suggests that the infrared sensor is suitable. However, infrared sensor requires that the sample is uncovered or has a system to open and close the container (like the semiconductor sensor), since the sensor diameter is 9mm. The thermocouple has a diameter of 0.5mm, this allows the magnetic fluid container there is only a small opening to open and close by itself. From the above it can be concluded that the thermocouple has more versatility.

REFERENCES


[28] MLX90614 family, Melexis.

AUTHORS PROFILE’

Fatima Mountadi (Mexican, 1967), holds a Master's degree in Satellite Broadcasting Systems and a Doctoral degree in Television Systems, Faculty of Broadcasting and Television at the Technical University of Communications and Information Technology in Moscow, Russia (MTUCH). She is a career professor in the Department of Electronic at the Faculty of Engineer- ing of the National Autonomous University of Mexico (UNAM). Her research interests include the areas of radiofrequency and biomedical, has published articles in congresses, national and international magazines and has a recognition as responsible of the thesis "Mobile Wireless Electrocardiograph Warning System", the winner of TR35 Mexico Magazine 2012 by MIT Innovation.

Pável Adolfo Figueroa Rodríguez (Mexican, 1985), She studied engineering in electronic systems, graduated from the National Autonomous University of Mexico. He is currently doing master's degree studies in electronic systems and researching of TV biomedical systems.