MODELLING AND TEMPERATURE REGULATION, USING A NEW MARERIAL FeNiCr ALLOY, IN INDUCTION COOKING DEVICE

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Résumé : The interest of induction cooking is direct temperature obtained on pan without thermal inertia. However to prevent overheating of the pan, it is necessary to obtain a well regulated temperature. For this aim, we propose to use a new material, FeNiCr alloy, placed outside in the bottom of the pan. In this paper, we model the magneto thermal phenomena of system by a finite element method (FEM) for the mean to determine the temperature evolution in the bottom of the pan taking into account the nonlinearity of system. This study shows, that a temperature value exceed the desired value of cooking (200 - 300°C) ,when using a conventional pan (stainless steel). In the aim to have a regulated temperature, a layer of new material, FeNiCr alloy, witch have a low Curie point (300°C), is placed in the bottom of the pan. This technique assures a natural regulation of temperature.

Keywords: Finite element method, Magneto thermal devices, Curie point, FeNiCr alloy.

1. INTRODUCTION
2.

Over the last ten year, induction cooking is much used, because of his several advantages [1] compared to traditional heating system (resistance, gas, etc...), in particular direct heating of pan without thermal inertia. The induction system (see Fig.1), comprises the inductor itself and a heated plate. The inductor is supplied by a medium-frequency power source (20 kHz) producing an alternating magnetic field, which causes eddy currents in the bottom of plate and therefore, Joule dissipation [1-2]. The temperature in the plate depends on the characteristics of the material which constitutes (conductivity σ, permeability μ).

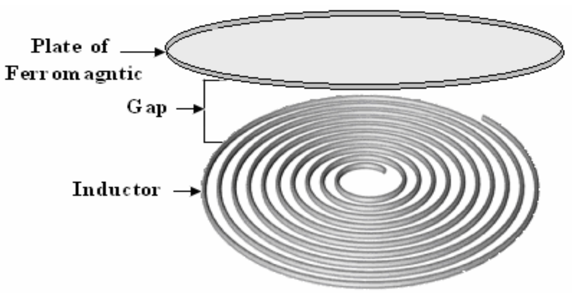

Fig.1: the modelled system

In this paper, firstly we determine the temperature evolution on pan bottom constituted with conventional ferromagnetic material, using magneto-thermal calculation method. Secondly, in the aim to have a regulated temperature, we propose a technique using a layer of new material, FeNiCr alloy [3], which has a low Curie point (300°C), who's placed in bottom of pan (Fig 2). The obtained results are compared.

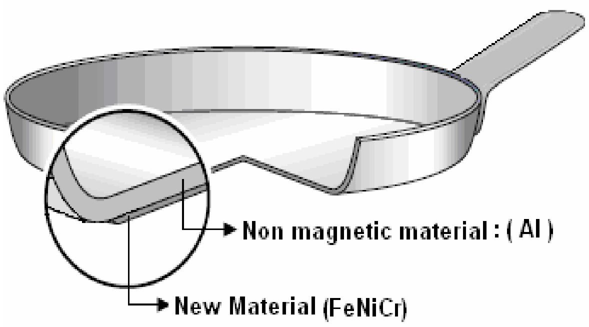

Fig .2: Pan with layer of FeNiCr

This paper is organized as follows: Magneto thermal Finite-Element analysis is presented in section 2. In section 3, we present the temperature evolution with conventional ferromagnetic pan. In section 4, the proposed technique is applied to obtain regulated temperature. Section 4presente results and discuss. Finally the conclusion is presented in section 5.

3. MAGNETO-THERMAL FINITE ELEMENT ANALYSIS

2.1 DESCRIPTIVE EQUATIONS

In order to know temperature evolution in the bottom of pan, which is the image of distribution of induced currents, it is necessary to solve the coupled Maxwell's and thermal equations. For the reason of axisymetric structure of the inductor, an axisymetric 2D solution is possible.
Using the magnetic potential **A,** electromagnetic phenomena are modelled by the well known magneto-thermal equation [4, 5]:

$$j\omega \frac{\sigma \overline{A}}{r} - \frac{\partial}{\partial r}\left(\frac{\nu}{r}\frac{\partial \overline{A}}{\partial r}\right) - \frac{\partial}{\partial z}\left(\frac{\nu}{r}\frac{\partial \overline{A}}{\partial z}\right) = \overline{J} \quad (1)$$

$$\lambda \nabla^2 T + q = \rho_m C_p \frac{\partial T}{\partial t} \quad (2)$$

$$q = \frac{1}{r^2}\sigma \omega^2 \overline{A}\,\overline{A}^* \quad (3)$$

A: Magnetic vector potential defined such as $\overline{A} = r\overline{A}_\theta$, A_θ : is the azimuthal component of the vector potential. ν is the magnetic reluctivity, σ is the electric conductivity, ω is the angular velocity, J is the current density, λ is the thermal conductivity, T is the temperature, q is the heat source density, ρ_m is the masse density, C_p is the specific heat and t is the time.

2.2 BOUNDARY CONDITIONS

The magneto-thermal analysis is performed by FEM (finite element method) using the governing equations (1) and (2) and the following boundary conditions (4) and (5):

$$Direchlet(A = 0) \quad (4)$$

$$-\lambda \frac{\partial T}{\partial n} = h(T - T_a) \quad (5)$$

h: is convection coefficient and T is ambient temperature.

The heat transfer coefficient in (5) has a role in determining the temperature distribution on the pan bottom of the device. Because of axisymetric structure of inductor, this makes h nonlinear due to the convection effect of the air nearby [6].

Thus we assume that h has a constant value (Table.1) along the radial direction of the axisymetric structure in studied system.

4. TEMPERATURE EVOLUTION IN PAN WITH CONVENTIONAL RERROMAGNETIC MATERIALS

The pan is made by a ferromagnetic stainless-steel. The curves σ(T) and μ (T), of the material, are shown respectively in Fig.3 and Fig4 [7].

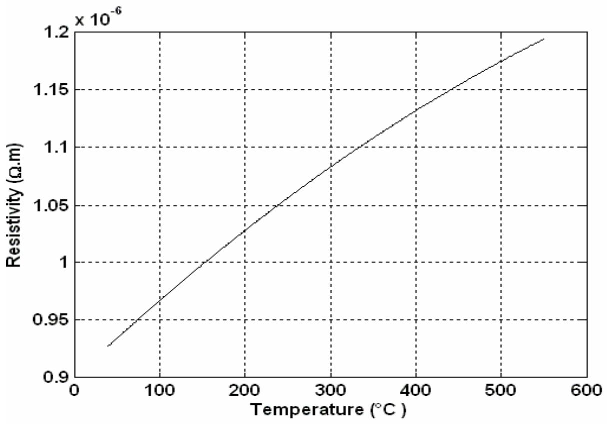

Fig.3. Curve of resistivity

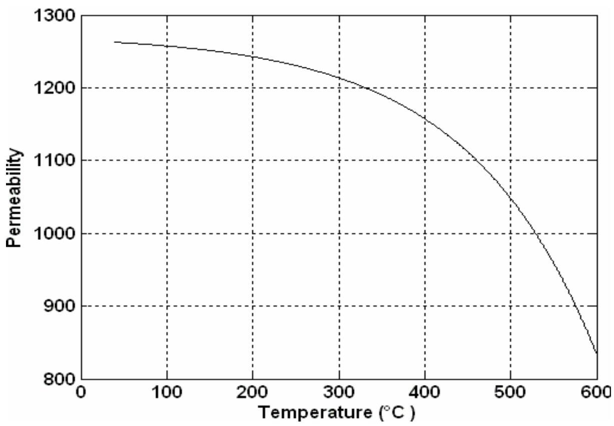

Fig.4. Curve of permeability

For heat the pan, we use an inductor with four throats containing coils (Fig.5). The other parameters shown in (Table1), except the conductivity σ(T) and permeability μ (T), can be assumed constant during the procedure of calculation for temperature.

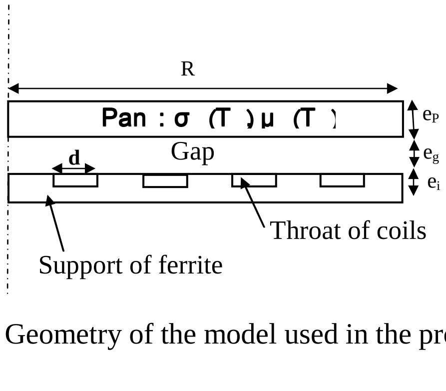

Fig.4. Geometry of the model used in the program

Table.1 Parameters of the simulated system

Symbole	Magnitude	Qantity
R	Radius of container	140 mm
e_i	Inductor thickness	3.8mm
e_g	Gap thickness	2mm
e_P	Pan thickness	1mm
d	Throat length	16.25 mm
e_q	throats thickness	2mm
μ_f	ferrite relative permeability	2500
f	Frequency	$20*10^3$ Hz
J	Current density	$2.5*10^6$ A/m^2
λ	Thermal Conductivity	26 W/m*°K
h	Convection coefficient	20W/m^2°C
ρ_m	Masse density	7700 kg/m^3
Cp	Specific heat	460 J/°C

The magneto-thermal calculation of our system is illustrated in flow chart of Fig.6.

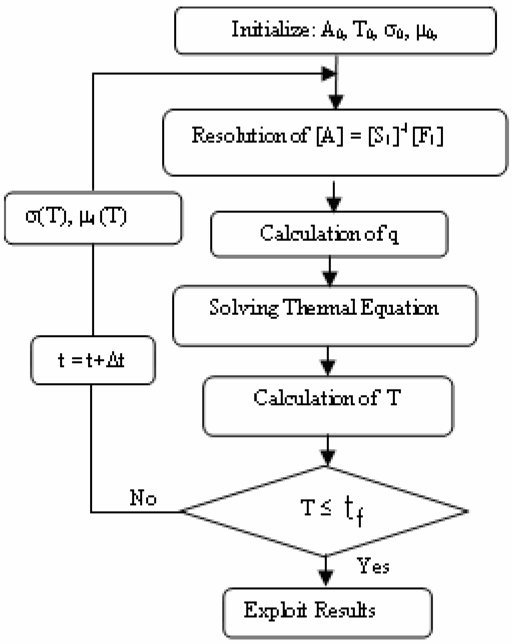

Fig.6. Flow chart of magneto thermal program

The thermal problem is solved step by step in the time using a step of 5 seconds.The temperature evolution versus time in a point situated at the middle of the pan is indicated in (Fig.7). The desired temperature (200-300) °C is obtained after a time of 70s, but we note that the temperature can achieve 455°C in permanent regime.

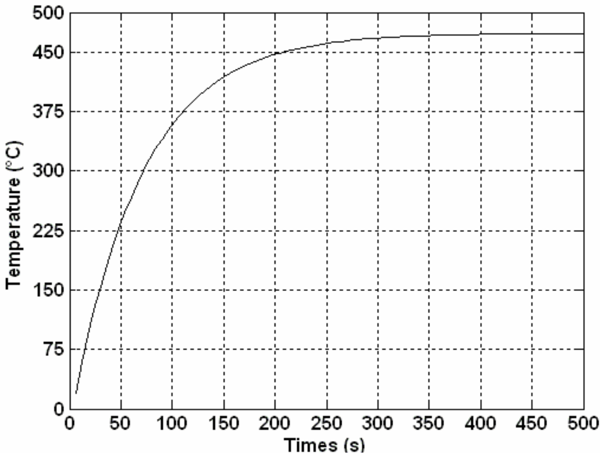

Fig.7. Temperature evolution of conventional material

5. Regulation temperature in pan with a layer of FeNiCr alloy

The main aim of this work is to suggest, a technique using a layer of new material, FeNiCr alloy, witch have low Curie point (300 °C) of , for natural limitation of temperature in bottom of the pan.

In order to obtain such solution, we consider a pan with a non magnetic material (Aluminium: ($\sigma = 37.10^6(\Omega.m)^{-1}$, μ_0) whose bottom is covered outside by a layer of FeNiCr alloy with a thickness e_L=3mm (Fig. 8). We use the same magneto thermal model as described in the section 3 taking the new magnetic and electric properties (μ (T), σ(T)) and thermal characteristics (λ, ρm and C_p),

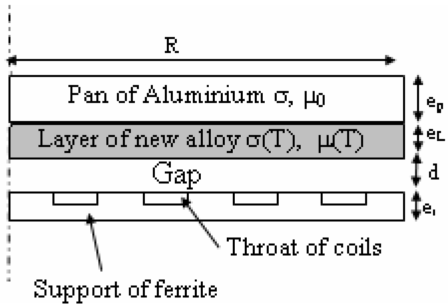

Fig.8: Pan with new alloy

4.1. ELECTROMAGNETIC CHARACTERISTICS OF FeNiCr ALLOY

We use three kinds of a FeNiCr alloy with a curie point at 300°C.

The electrical conductivity σ(T) and the magnetic permeability μ (T) of the these materials are expressed as [8]:

$$\sigma(T) = \frac{\sigma_0}{1+\alpha T} \qquad (6)$$

$$\nu(T) = \nu\left(1 - e^{\frac{T-300}{150}}\right) \qquad (7)$$

$\rho_0 = 1/\sigma_0 = 13.75 \cdot 10^{-8}\Omega.m$;

$\alpha = 0.004$;

$\rho(T) = 1/\sigma(T)$ and $\mu(T) = 1/\nu(T)$.

The curves of σ(T) and μ (T) are shown respectively in Fig.9 and Fig.10. The values parameters thermal are shown in Table2.

Table.2 : Characteristics of different FeNiCr alloy

Item	New ferromagnetic material FeNiCr alloy	Masse density ρ_m (kg/m^3)	Specific heat Cp(J/C°)	Thermal Conductivity λ (W/m°K)	μ_r (Tc= 300°C)
1 [9]	Nickel (32-35) % Chromium (20-23) %	8000	450	11.6	1273
2 [9]	Nickel (36-39) % Chromium (26-30) %	8000	500	14.6	1273
3 [10]	Fe-Nickel-Chromium alloy	7849	460	59	1273

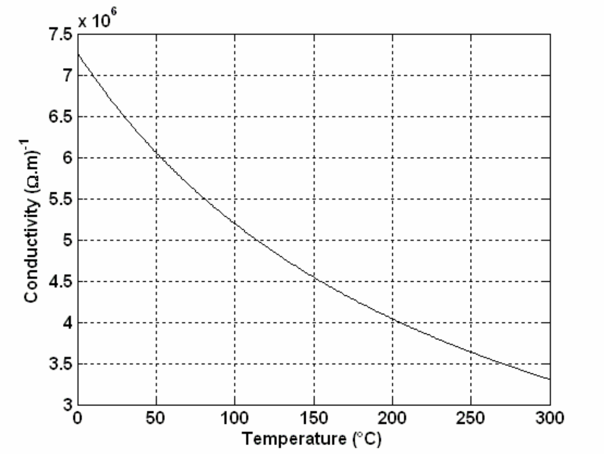

Fig.9: Curve of conductivity

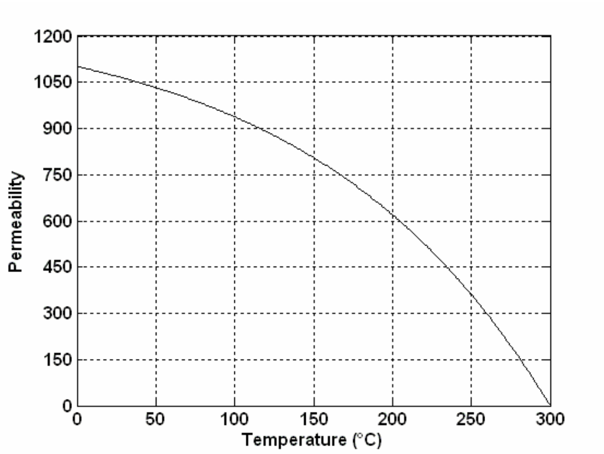

Fig.10: Curve of permeability

6. RESULTS AND DISCUS

The temperature results using the three kind of FeNiCr alloy are presented in (Figures :11,12 and13).

In induction heating system, the use of material with low value Curie point assures a natural regulation, and limits the temperature rise beyond that value.

At the beginning of the heating, the material (pan) has a considerable value of permability which concentrates electromagnetic field. However the induced current is considerable and therefore the temperature evolution increases quickly versus time. Once, the temperature approaches the Curie point, the permeability of material decrease until μ0, causing the decrease of the induced current. This last phenomenon assures a natural regulation of the temperature.

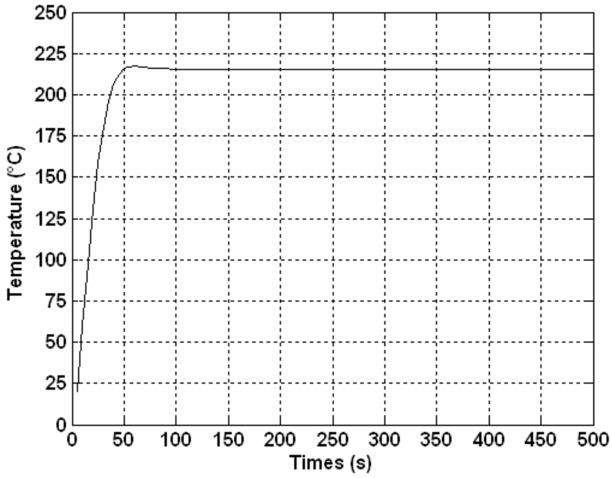

Fig.11: Temperature evolution of material: 1

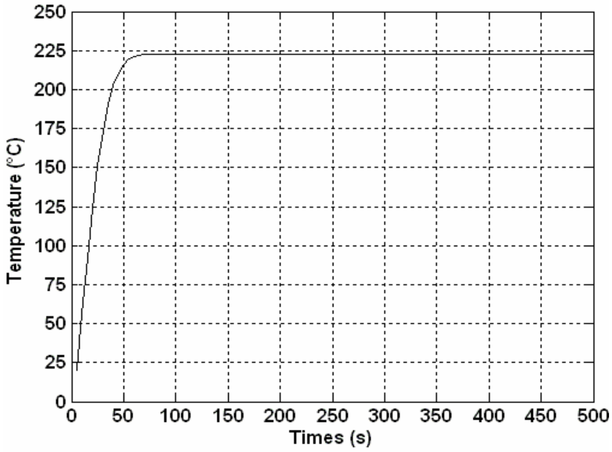

Fig.12: Temperature evolution of material: 2

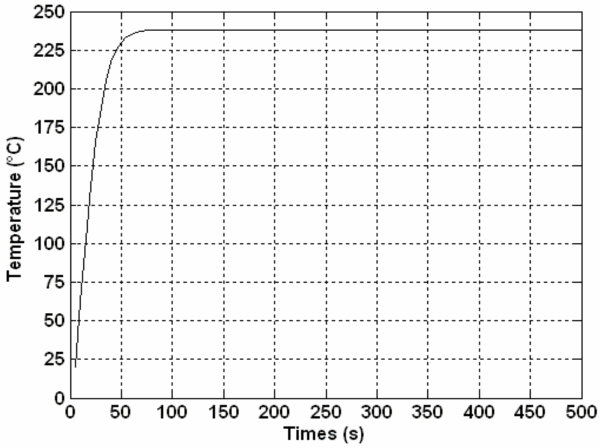

Fig.13: Temperature evolution of material: 3

7. CONCLUSION

In This paper, a new material FeNiCr alloy has been used, for a regulation of the temperature in induction heating system. The simulation result shows that the proposed technique gives a well regulation of temperature compared to the use of conventional material. The use of FeNiCr alloy at (300°C) Curie point, assure a natural regulation of temperature between 200°C and 300°C which is suitable for the induction cooking system.

The validation of the results obtained is qualitative. Quantitative validation can be done in the study of complete system for which experimental results are available and could be a prospect of this study.

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