Chapter 4

Magnetodielectric Materials – Use in Inductive Heating Process

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Additional information is available at the end of the chapter

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1. Introduction

In the induction heating processes, the main problem is to increase process efficiency, which can be achieved through the intervention of different parts of the installation [9,10,11]

A method used to increase electrical energy conversion efficiency, which is referred to in the literature and that also was considered in the study discussed in this paper is to use magnetic flux concentrator[1,2,6]. If we analyze the structure of hypothetical wound inductors, located close to a work piece, as shown in Figure 1, we can see that for this structure is equivalent electric circuit in Figure 2.

Ohm's Law applied to the magnetic circuit is:

$$NI = R_m \times \Phi_i \tag{1}$$

The magnetic reluctance equivalent of the system consists of two parallel reluctance: magnetic reluctance of the work piece R_{mp} and the air gap magnetic reluctance between spiral inductors and piece of heated, R_{ma}, in series with the magnetic reluctance of outside environment, Rme, of the inductor coils

If the magnetic reluctance of the piece, R_{mp}, depends on the material characteristics, and the air gap reluctance R_{ma} can not be reduced below a value that depends on technological conditions of the heating process, remains the method of intervention to reduce the equivalent reluctance of the system, improving the environment reluctance outside coils inductors, R_{me}.

This is actually the role of magnetic field concentrator using in inductive heating processes.

To achieve these magnetic concentrators in practice it is using a variety of materials and could therefore be useful brief review of their focusing on magnetodielectric materials made and used in the study approached the work.

Requirements of magnetic materials in induction heating applications can be very severe in many cases[1,8]. They must operate within a broad category of frequencies, to possess permeability and high saturation flux densities, have stable mechanical properties and resistance to high temperatures caused by heat loss due to magnetic concentrators and heat transferred from the heated parts.

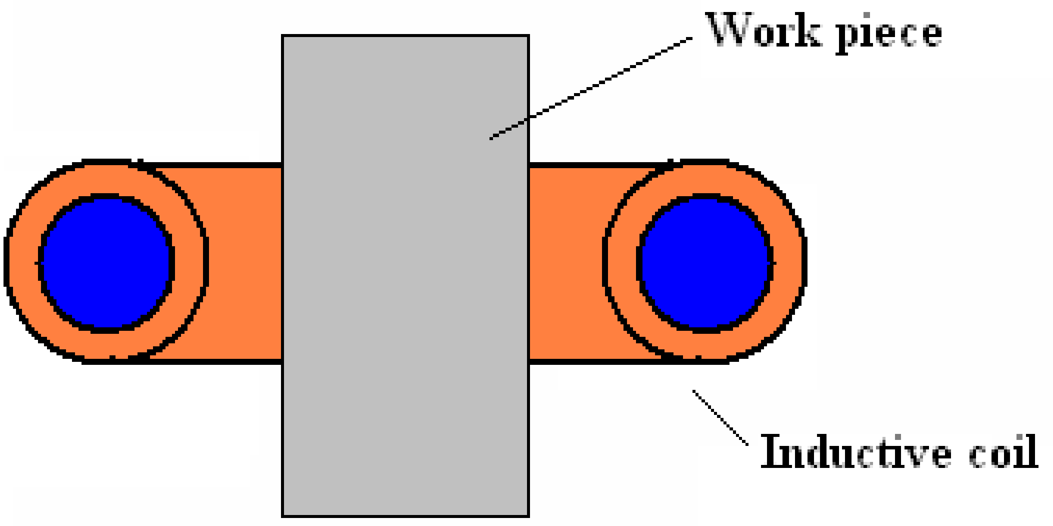

Figure 1. Hypothetical structure of an inductor – work piece of heated

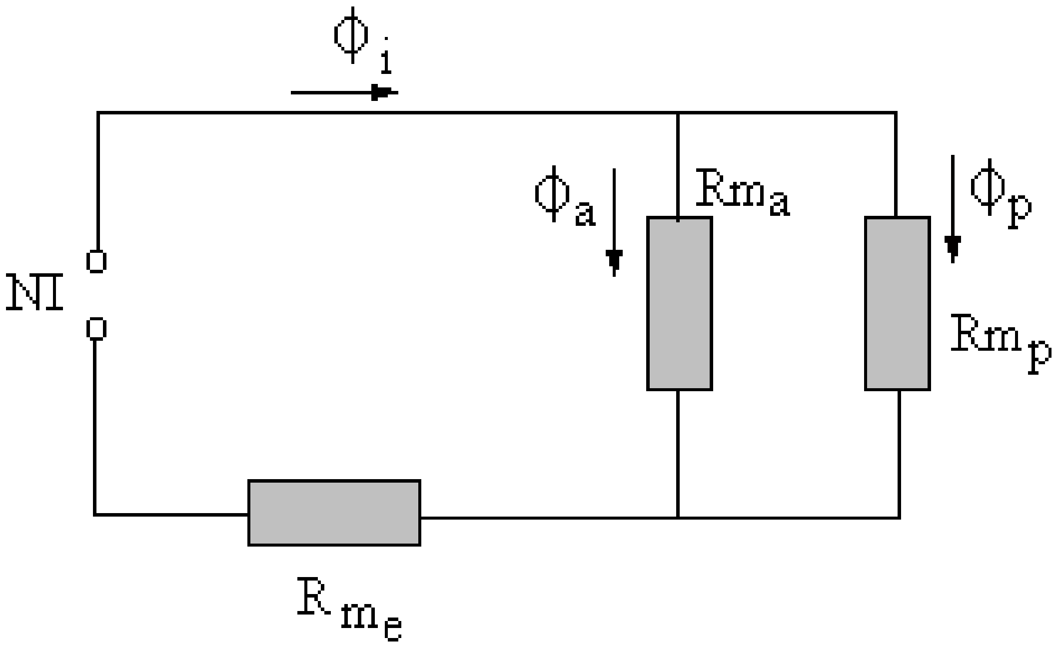

Figure 2. Equivalent electric scheme of Inductor - heated piece

Three groups of magnetic materials can be used to concentrate the magnetic flux: laminates, ferrites and magneto dielectric materials, so-called MDM materials.

Figure 3. present variation curves B = f (H), compared to laminated, ferrite materials and MDM [1,2,6], used in magnetic field concentrator construction.

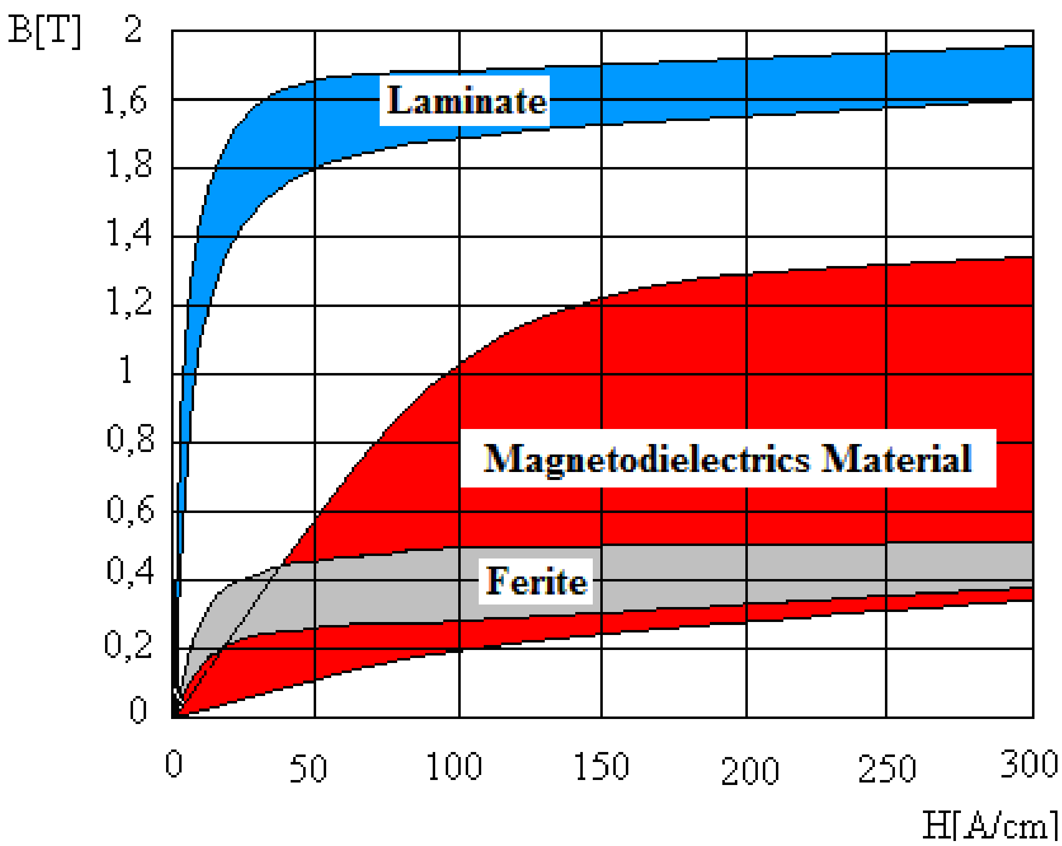

Figure 3. B=f (H) curves [1;2,6]

2. Magnetodielectric materials

These materials are composite materials made of magnetic particles and dielectric materials that serve as links and electrical insulators of magnetic particles. Magnetic properties of magnetodielectric materials (MDM), depend on constituent particle properties, their shape and volume. Mechanical and thermal characteristics depend mainly on the ratio of magnetic material, and dielectric material. The general properties of materials depend by manufacture technology, their achievement, given the fact that their production involves a pressing process, who making certain properties, especially magnetic to manifest differently on different axes.

The world leader in the manufacture of MDM is FLUXTROL Company, which made several types of magnetodielectric materials [6].

In those that follow will present the results of several studies made by the authors, to obtain a magnetodielectric material by using it in inductive heating processes.

To achieve magnetodielectric material was used dielectric material, consisting of two components manufactured epoxipoliamidic resin without solvents, that drying to 80 ° C.

Mixing ratio of components A / B is 2/1 parts by weight. The product is used in electrical engineering, as mass of hardware, building and construction fill in some details of engines and generators, to strengthen the drum and clutch electromagnetic coil for sticking carcasses and broken cylinders from large and small electrical transformators.

Technical characteristics of electro-mass (dielectric material):

a. Features delivery

Features delivery	A Component	B Component
Aspect	Mush mass	Mush mass
Colour	gray	gray
Specific weight [g/cm3]	1.7 - 1.5	1.25-1.30

Table 1.

Curing time at:	23°C	is	8 hours
	80°C	is	1 hours
	120°C	is	30 minute

Processability time: 30 min.

b. Mechanical properties of hardened product

Mechanical properties	
Tensile resistance [kgf/cm]	190
Compresion resistance[kgf/cm]	800
Bend resistance [kgf/cm]	200

Table 2.

c. Electrical properties

Electrical properties	
dielectric rigidity [kV/mm]	14
Surface resistivity [Ω]	5*1012
Volume resistivity [Ωcm]	3*1014

Table 3.

Characteristics were determined on specimens cold hardened for 7 days

3. Experimental determination of magnetodielectric material resistivity

To achieve the intended purpose of the topic to increasing power conversion efficiency in the heat study was done to achieve magnetodielectric material samples based on ferromagnetic particles, embedded in electro-mass.

In the first phase of research was done a rectangular plaque, the dimension of them it is shown in Figure 4.

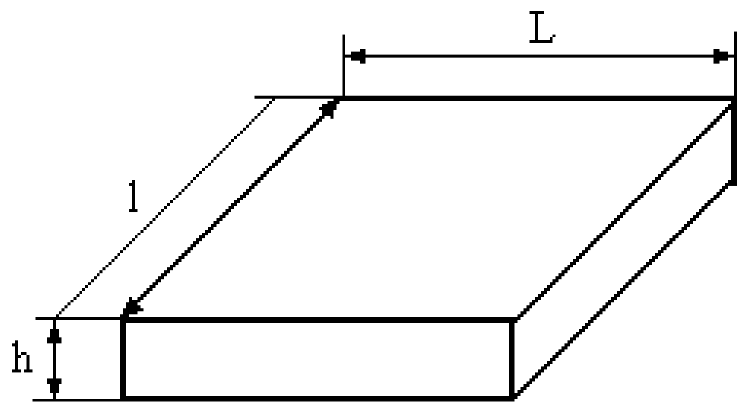

Figure 4. The dimension of the rectangular plaque

The dimension of the rectangular plaque are :

L = 46,6 mm
l = 16,5 mm
h = 8,2 mm

The magnetodielectric material was made by mixing the ferromagnetic metal powder 68%, with 32% resin of the type shown in the previous subsection. Material sample is placed between rectangular form electrodes of a measuring device whose scheme is shown in Figure 5

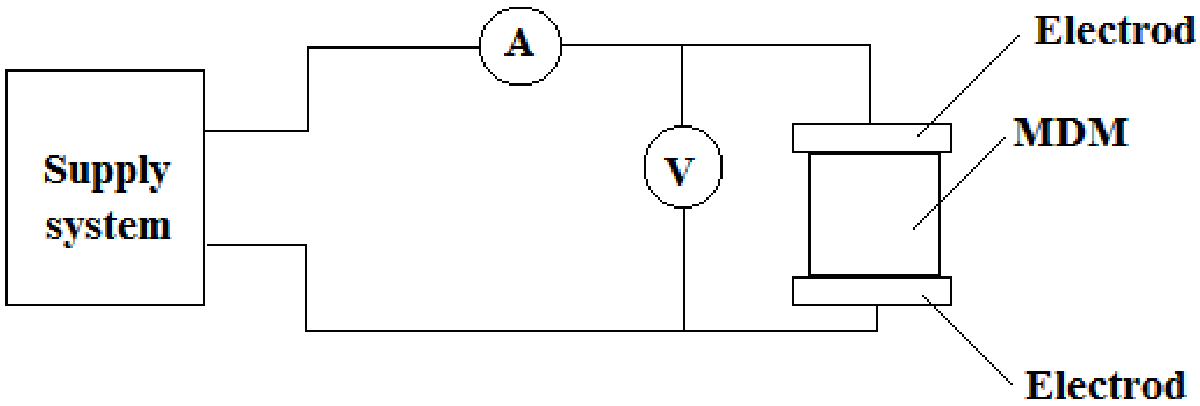

Figure 5. Module scheme used to determine resistivity value

The supply voltage is set at 100V and it was make determinations of the resistance of the sample and on the base of the sample size it was calculated the material resistivity. The determination, at different temperatures of the ambient, by heating the specimen of the MDM in a thermostatic oven, it was repeat.

The results are presented in the following table.

Average values of the coefficient of variation of resistivity with temperature, is $\alpha = 51,10$

Curve of variation of resistivity with temperature, obtained for this type of material is shown in Figure 6.

Nr. det	U [V]	I [mA]	R [Ω]	ϱ [Ωm]	T [^{0}C]	α
1	100	3,14	31840	738,05	26	
2	100	1.14	87710	2033,11	40	24,54
3	100	1,02	98030	2272	50	46,32
4	100	0,12	833000	19308,9	60	74,98
5	100	0,017	5714280	132457	70	58,59

Table 4.

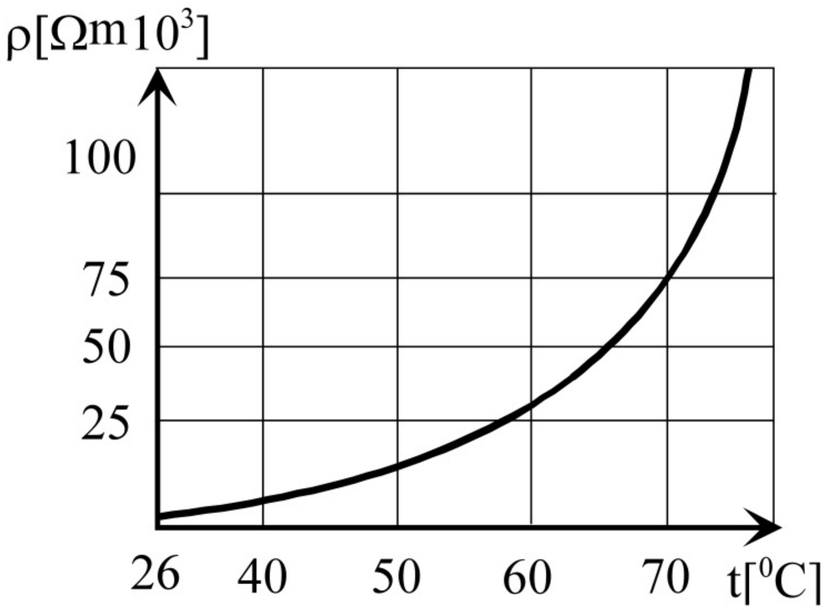

Figure 6. Variation of resistivity with temperature

4. Determination of the curve B = f (H) for magnetodielectric material

To determine this curve was used fluxmeter method. For this, was done a sample of material with thoroidal shape and that were winding two coils. Figure 7 is showing the shape and the dimension of the MDM sample.

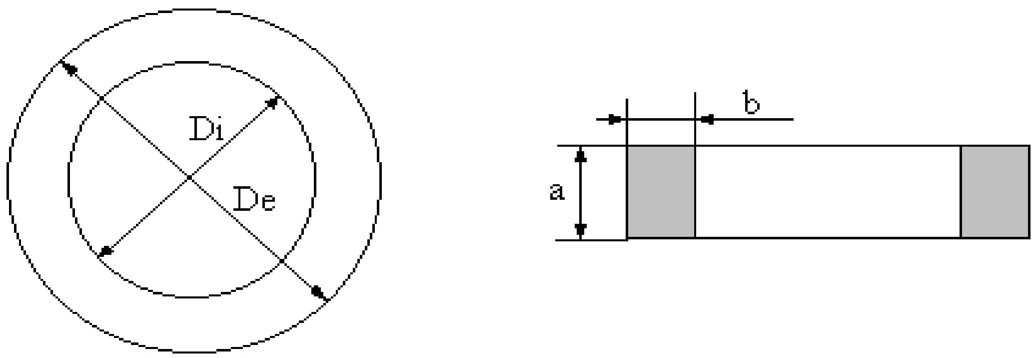

Figure 7. The dimension of the MDM sample

The dimension of the thoroidal sample is:

De = 46 mm
Di = 34 mm
Dm = 40 mm
a = 6mm
b = 6mm
Number of turns in primary :N1= 368
Number of turns in secondary :N2= 1

Scheme used to determine the dependence B = f (H) is shown in Figure 8

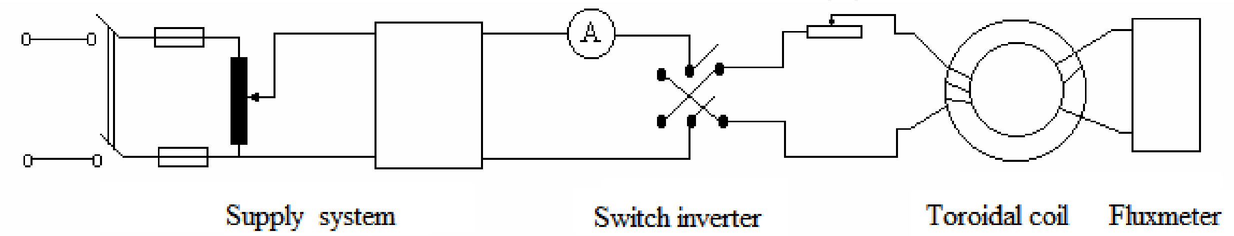

Figure 8. Scheme used to determine the dependence B = f (H)

Magnetic field is calculated with relation:

$$H = \frac{N_1 \cdot I}{\pi \cdot D_m} \quad \left[\frac{A}{m}\right] \tag{2}$$

and magnetic flux density is given by the expression:

$$B = \frac{\Phi}{2N_2 \cdot S} \tag{3}$$

where S is the section of the toroidal core magnetodielectric material.

Measured and calculated values are presented in the table 5.

Figure 9 show the first magnetization. With [*] are the values which have been determined from measurements

5. Inductor modeling with field concentrator

Given the advantages of concentrator field magnetodielectric materials, in this case study was modeled an inductor, witch use a concentrator field made by magnetodielectric material, by the type obtained, by using modeling and numerical simulation with FLUX2D software[4].

The field concentrator made of magnetodielectric material, have the following materials data:

- Relative permeability - constant scalar model, the value 108
- Resistivity - constant scalar model, the value 40 000 Ωm.

I [A]	Φ [mWb]	*B[T]*	H [A/cm]	I[A]	Φ [mWb]	*B[T]*	H [A/cm]	I[A]	Φ [mWb]	*B[T]*	H [A/cm]
1	0,15	0,1	21	1	0,15	0,1	21	1,5	0,01	0,08	31,52
1,5	0,3	0,2	31,52	1,5	0,15	0,1	31,52	2	0,01	0,08	42
2	0,45	0,3	42	2	0,3	0,2	42	2,5	0,15	0,1	52,54
2,5	0,75	0,6	52,54	2,5	0,37	0,3	52,54	3	0,15	0,1	63
3	0,9	0,7	63	3	0,37	0,3	63	3,5	0,15	0,1	73,56
3,5	1,2	1	73,56	3,5	0,6	0,5	73,56	4	0,15	0,1	84
4	1,35	1,1	84	4	0,6	0,5	84	4,5	0,3	0,2	94,58
4,5	1,35	1,1	94,58	4,5	0,6	0,5	94,58	5	0,3	0,2	105
5	1,05	0,9	105	5	0,52	0,4	105				
4,5	0,9	0,7	94,58	4,5	0,45	0,3	94,58				
4	0,75	0,6	84	4	0,6	0,5	84				
3,5	0,75	0,6	73,56	3,5	0,6	0,5	73,56				
3	0,6	0,5	63	3	0,52	0,4	63				
2,5	0,45	0,3	52,54	2,5	0,3	0,2	52,54				
2	0,3	0,2	42	2	0,15	0,1	42				
1,5	0,15	0,1	31,52	1,5	0,15	0,1	31,52				
1	0,01	0,08	21	1	0,01	0,08	21				

Table 5. Measured and calculated values

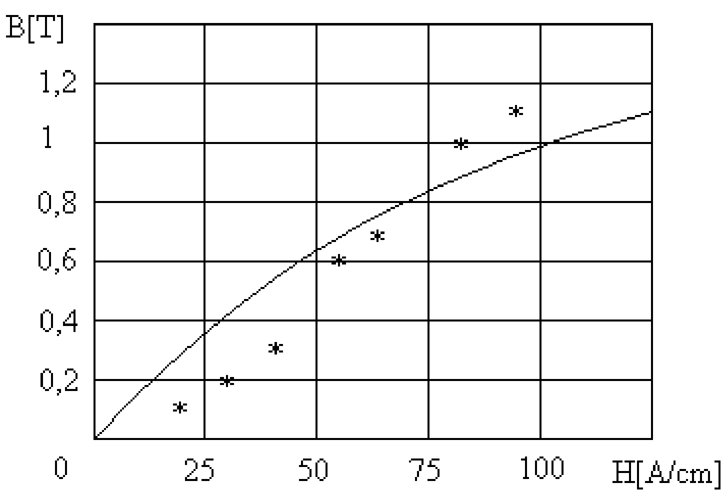

Figure 9. Dependence B = f (H).

Geometry made for this case is shown in Figure 10.

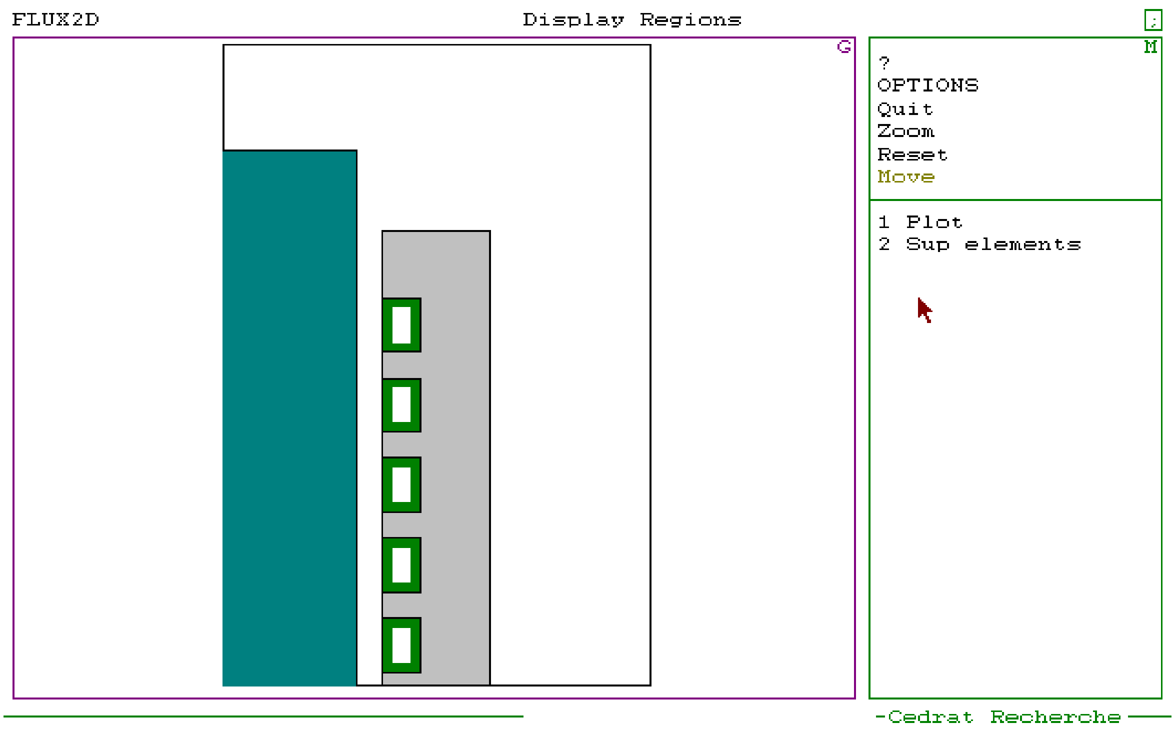

Figure 10. Inductor geometry for monolayer inductor with field concentrator

Was analyzed for this case, the power density distribution in the work piece - Figure 11. , and temperature variation on a point on the surface during the heating process - Figure 12.

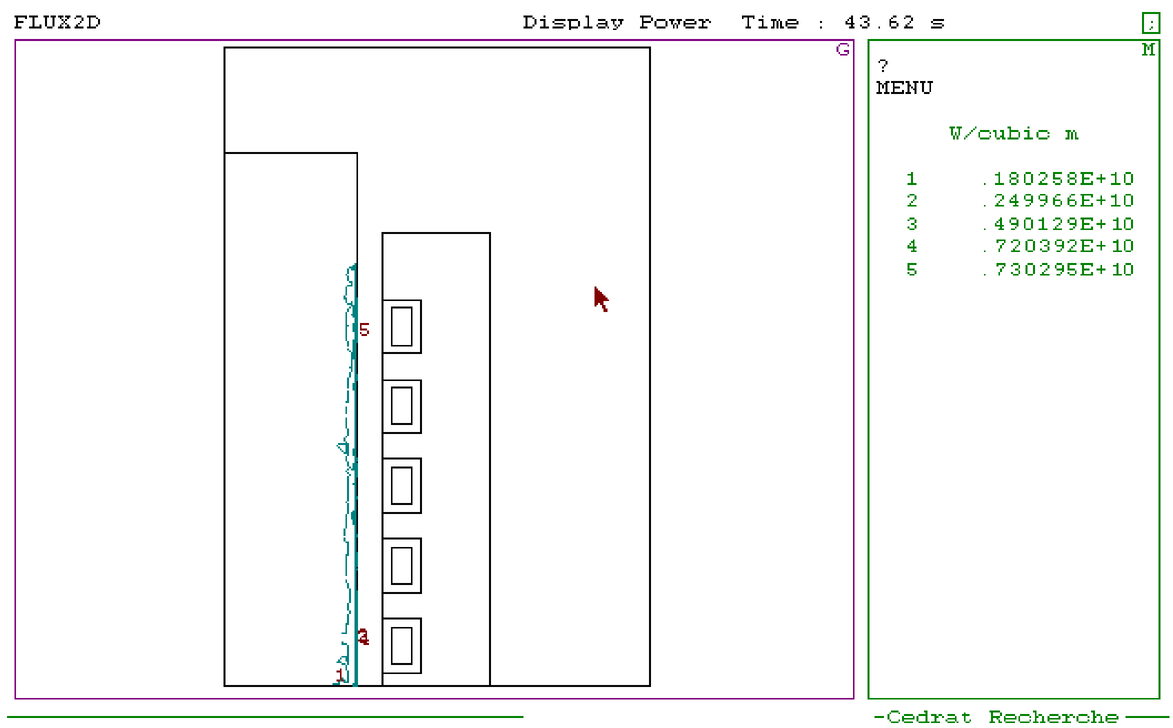

Figure 11. The power density distribution

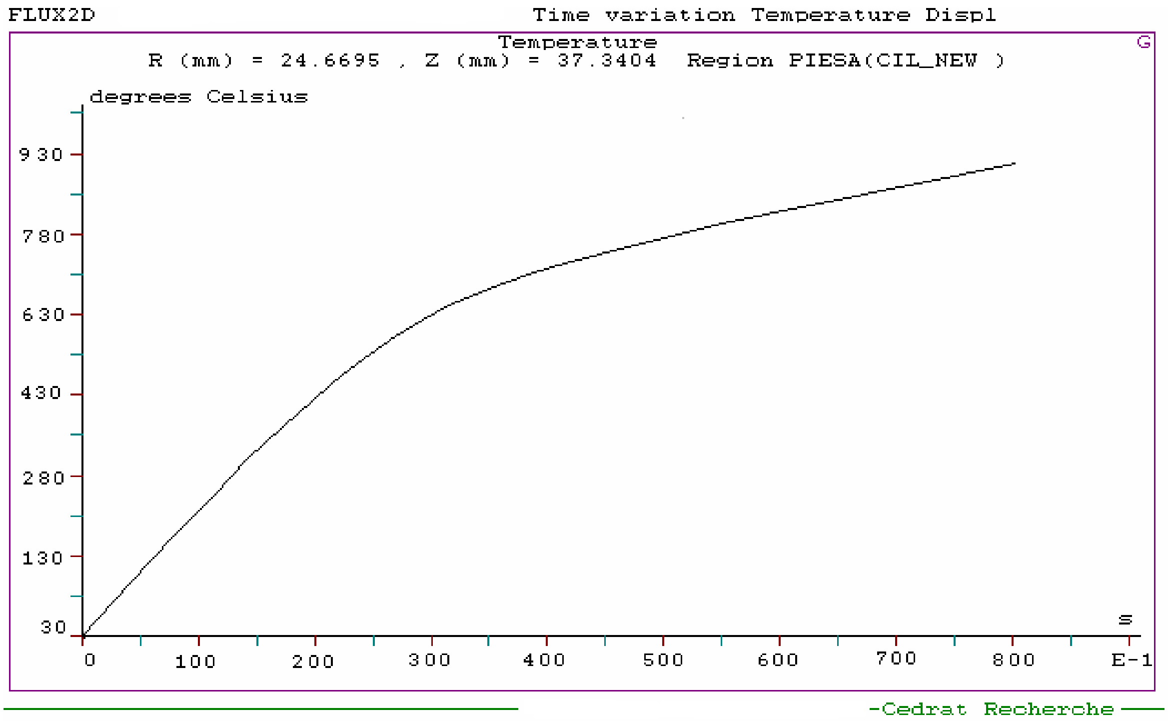

Figure 12. Temperature variation

Based on the results of modeling and simulation was made an inductor with magnetodielectric material concentrator. The image of this inductor during the heating process is shown in the figure below.

Figure 13. The inductor during the heating process

Current drawn from the supply of inductive heating during the process was 60A, and the measured line voltage was 378V.

The initial temperature of the work piece and the concentrator of magnetodielectric material used were 12^0C. Final temperature of the work piece at the end of heating processing was 840^0C, temperature reached during the 80s. Final temperature of the outer surface of the concentrator field at the end of the heating process was 14^0C.

6. The electrical efficiency in inductive heating processes who magnetodielectric field concentrators use

The primary endpoint of this chapter is evidence increased electrical energy conversion efficiency, in the inductor-piece ensemble, that use a magnetodielectric material field concentrator of the type obtained as explained above.

Efficiency for this case, determined from data modeled is:

$\eta_{\text{i could reg}} = 96\%$
$\eta_{\text{i hot reg}} = 69\%$

For the heating inductive process, without magnetodielectric field concentrator calculated is:

$\eta_{\text{i could reg}} = 81\%$
$\eta_{\text{i hot reg}} = 54\%$,

There is a significant increase of 15% for hot and cold regime of electrical energy conversion efficiency, the inductor-piece ensemble.

These values increase efficiency reveal clearly the advantage of using electromagnetic processing systems for heating that are made up of field concentrators made by magnetodielectric materials

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