Proceedings of "National Conference on Emerging Trends in Science and Advances in Engineering"
Organized by Phaltan Education Society's College of Engineering Phaltan, www.coephaltan.edu.in
International Journal of Innovations in Engineering Research and Technology [IJIERT]
ISSN: 2394-3696, Website: www.ijiert.org, July, 2023

OPTIMIZATION OF WALL MATERIAL FOR MINIMUM HEAT LOSSES FOR INDUCTION FURNACE BY FEA

1. Mr. Nitin B. Bhujbal, Lecturer, *Department of Mechanical Engineering College of Engineering , Phaltan,* bhujbalni3@gmail.com
2. Mr. Aditya H. Jadhav, Lecturer, *Department of Mechanical Engineering College of Engineering , Phaltan,adityajhdhav.ahj@gmail.com*
3. Ms. Pratima C. Bhosale, Lecturer, *Department of Mechanical Engineering College of Engineering , Phaltan, pratimabhosale9645@gmail.com*
4. Ms. Asha K. Dudhal, Lecturer, *Department of Mechanical Engineering College of Engineering , Phaltan, ghanwatasha22@gmail.com*

ABSTRACT

Induction furnaces are commonly employed for melting metals, and to prevent losses, silica ramming mass is typically used as a refractory material. Consequently, it is crucial to optimize the thickness of the refractory material.

This research paper focuses on optimizing the wall thickness and material to minimize heat losses during the iron melting process. Calculations involve determining thermal properties and physical parameters for heat loss calculations. Theoretical heat loss and temperature distribution calculations are then compared to actual measurements obtained from an existing furnace, which experiences significant losses.

To perform the optimization, ANSYS Software was utilized, providing more accurate results in a shorter timeframe. The problem was approached in an axi-symmetric manner since it exhibits symmetry about the Y-Axis. Ultimately, it was concluded that optimizing the thickness of the refractory material could reduce losses by 35%, while optimizing the thermal properties could lead to a reduction of 73% in losses. By employing the proper thickness and material properties for the refractory material in the induction furnace, losses can be ultimately reduced by 70%.

Key words: Induction heating, optimization, coreless induction furnace, thermal conductivity, silica ramming compound, micasil.

1. INTRODUCTION

In today's world, the demand for electric power is increasing, and there is a focus on its economical utilization. This has led to the development and production of energy converters with higher power capacities. Additionally, minimizing electric power losses and protecting the environment have become crucial considerations, particularly in terms of reducing heat losses. These heat losses primarily occur through conduction, convection, and radiation. Therefore, it is necessary to enhance the refractory material and optimize the wall thickness of the refractory material [1] and [2].

The optimization of power equipment geometry is highly relevant in the present time, and numerous studies have addressed the issue of heat loss [3]. Both core type or channel furnaces and coreless induction furnaces are well-established designs in the industry. The existing furnace under consideration is one of the largest commercial units capable of melting approximately 12 tons per hour, with a high-power density of around 1800 kWh/ton, enabling the melting of a cold charge within 50 to 60 minutes [1].

The primary objective of this paper is to identify issues related to the induction furnace and calculate heat losses across the temperature distribution using analytical methods. The analytical results are compared with actual measurements taken from the existing furnace, which are further validated using APDL Ansys software. A model is created in ANSYS software based on the existing dimensions and is verified against the calculated results [4] and [5]. Optimal changes in the geometry of the induction furnace and the properties of the wall material are made using ANSYS software to minimize heat losses. This paper aims to study the impact of process parameters on energy consumption and identify potential optimizations for the refractory material of the induction furnace.

2. LITERATURE SURVEY

Prof. N. C. Mehta and colleagues conducted a thorough examination of thermal fatigue in Induction Melting Furnaces, which are extensively utilized for melting various materials in modern times. They utilized ANSYS software to analyze the ramming mass and determined the stress distribution across the refractory wall. Their findings indicate that critical stress can be reduced, leading to an improved lifespan of the refractory wall. Additionally, they observed that the refractory material tends to lose its thermal properties within a lifetime of 200-400 hours.

Hong-Seok Park, Xuan-Phuong Dang, and their team focused on enhancing the efficiency of the manufacturing process. They worked on optimizing the operating parameters of the induction heating system and proposed the use of thermal insulation to minimize heat losses. Their research concluded that energy efficiency can be increased by up to 6%. Furthermore, by implementing insulating devices to reduce radiation and convection, an additional 4% of energy can be saved after optimization.

M. M. Ahmed, M. Masoud, and their collaborators reviewed the design of coreless induction furnaces specifically for melting iron. They determined the electrical parameters of the furnace, such as the number of turns in the coil, coil inductance, coil resistance, and maximum flux density, based on the transformer concept. They then compared their design results with the existing design to evaluate their effectiveness.

3. STUDY OF EXISTING FURNACE

A. Geometry

The coreless induction furnace consists generally a Crucible, inductor coil, shell, cooling system and tilting Mechanism. The crucible is formed from refractory material. This crucible holds the charge material and subsequently the melt. The choice of refractory material depends on the type of charge, i.e. acidic, basic or neutral. The durability of the crucible depends on the grain size, ramming technique, charge analysis and rate of heating and cooling the furnace [4]. The geometric shape like width, height of each material of the Furnace is shown in fig.1

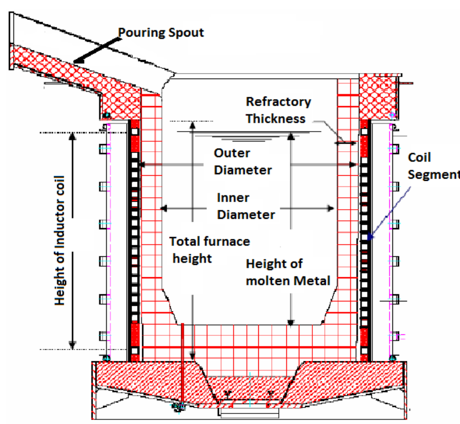


Fig.1.The geometry of the furnace

B. Analytical study

In this study, it has been determined that calculating heat conduction through a composite cylinder is the suitable approach for evaluating heat losses and temperature distribution in the furnace [6], yielding precise outcomes. Occasionally, assumptions may be necessary during heat loss calculations.

Mathematical calculations require temperature measurements at the inner and outer walls of the furnace, as well as the thermal conductivity of each material involved. Hence, it is essential to employ appropriate instruments for temperature measurement and accurately determine the physical dimensions. The measured temperatures are presented in Table 1.

Table1. Temperature distribution in existing induction furnace

Notation	Content	Temperature °C
Ti	Inner wall temperature	1500
To	Ambient temperature	40
Tw	Outer wall temperature	40 to 75
Twi	Inlet water temperature	25 to 35
Two	Outlet temperature of water	40 to 75

Following are measured geometrical dimensions on existing furnace and the properties of material at 1500°C have presented in table2.

Table 2. Dimensions and properties of existing furnace:

Material	**Dimensions in mm**		**Thermal Properties**	**Units**
	Diameter	Thickness		
Coil core cement	1550	10	K = 1.39	w/m ^{0}C
			h = 30	W/m2 ^{0}C
Micasil	1530	3.5	K = 0.12	w/m ^{0}C
Ramming mass	1200	160	K = 11	w/m ^{0}C
			h = 200	W/m2 ^{0}C

4. HEAT LOSS CALCULATION:

Heat loss can be calculated by referring electrical circuit for steady state condition of composite cylinder [6]. From given data in table1 and table2 we can calculate conduction, convection and radiation losses with temperature distribution.

A. Heat loss calculation:

1. Calculation of resistance **R = ln (r2/r1) / 2πLk**
   Total resistance **∑R = R1+R2+R3**
2. Conduction losses **Q = (Ti – To) / ∑R**
3. Radiation losses **$Q = \varepsilon A \sigma (Ti^4 - To^4)$**
4. Convection losses **Q = h A (Ti – To)**
5. Total heat losses from furnace **Q = Q convection + Q radiation + Q conduction**
6. **Total heat flux = Heat generated / 2πrl**

Q = Total heat loss from furnace in W
To, Ti = Temperatures at outlet and inlet in °C
K = Thermal conductivity of material of wall in w/m °C
h = Heat transfer coefficient from outer surface of wall in W/m2 °C
b = Thickness of wall in mm
ε = Emissivity of red-hot body = 0.43

A = C/S area of the furnace
σ = Stefan Boltzmann constant = 5.669 x e-8

Table 3. Calculated heat loss and temperature distribution is shown in following table

Heat loss kWh			Total loss kWh	Temperature °C			
Conduction	Convection	Radiation		T1	T2	T3	T4
309	297	140	746	1500	435	265	76

B. Comparison between Actual and analytical results:

To verify the design results, a comparison between total heat loss and temperature distribution of calculated results and actual results of induction furnace were carried out, which are tabulated below in table 4. From this table it can be seen that the analytical values are close to the actual ones.

Table 4. Verification of calculated value with actual value

Method	Temperature °C				Heat loss kWh
	T1	T2	T3	T4	
Actual Value	1500	-	-	76	720
Analytical value	1500	436	265	72	746

Table indicates that there are very huge losses in furnaces. So, there is potential to reduce heat losses with optimization of geometry and properties of refractory material. If these losses of 746 kWh are considered economically then there will be huge losses. Economic rate is 7.28 Rs/unit, so per year directly crores of rupees is going to be wasted with the power losses.

5. MODELING IN SOFTWARE

The accurate analysis of Induction melting furnace refractory wall is done for finding out temperature distribution, heat flow [1]. These conditions include initial and boundary conditions, material properties and assumptions (if required).

5.1 Analysis of existing model of furnace

Based on drawing and dimensions a model of existing furnace is developed using APDL Ansys. Problem is symmetric about Y-Axis so for better result and accuracy we can achieve with Axi-symmetric condition. Analysis is done with static thermal analysis because of its actual measurement and parameter which is collected at steady state[6]. We have done three kinds of meshing i.e. course, normal and fine meshing [1]. Then we had selected normal mesh density which gave 25806 nodes and 25181 elements. In FEA, Axi-symmetric modeling of furnace geometry with the three materials with APDL Ansys for Static thermal analysis is carried out. All materials were modeled by quad mesh types with smart size 1 for all areas.

PLANE55 can be used as a plane element or as an axisymmetric ring element with a 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The element is applicable to a 2-D, steady-state or transient thermal analysis. The element can also compensate for mass transport heat flow from a constant velocity field.

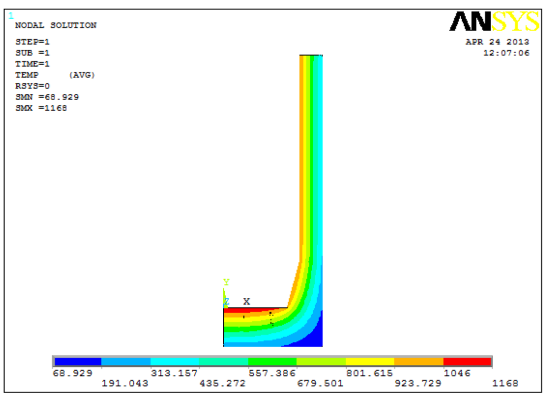
5.2 Boundary condition

To solve this heat transfer problem of induction melting furnace wall, the following initial and boundary conditions, material properties are made:

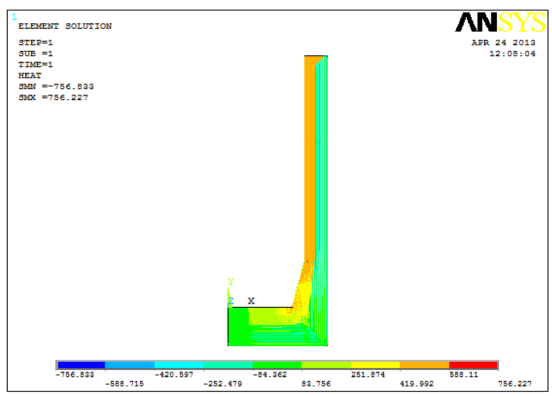
- Ambient Temperature is 40 °C.
- Apply heat convection over the inner and outer wall.

The boundary conditions are introduced into module ANSYS by Choosing the static mode of analysis. First of all, define the physical dimensions of material and then thermal properties. At boundary condition the convection at inner and outer wall of the furnace should be applied.

Results of existing induction furnace with the APDL Ansys software:



A. Temperature distribution curve



B. Heat flow

If we go for very fine meshing or very course meshing accuracy is not obtained. So normal mesh density is selected which will give closer value to actual value. Thus, mesh density is found. It was found that meshing does not affect temperature distribution but affected the heat flow and heat flux.

5.3 Verification with the analytical results

It is needed to verify analytical and software results. Once verification is done, we can optimize the geometry and properties for to minimum heat losses from the induction furnace. Table 5 shows the verification of analytical and software results.

Table 5 Analytical and software Result verification

Method	Temperature ^{0}C			Heat flow kWh
	T2	T3	T4	
Software	436	191	68.92	756.22
Analytical	436	265	76	746

The verified values of calculated results by using software are closer to actual measured values.

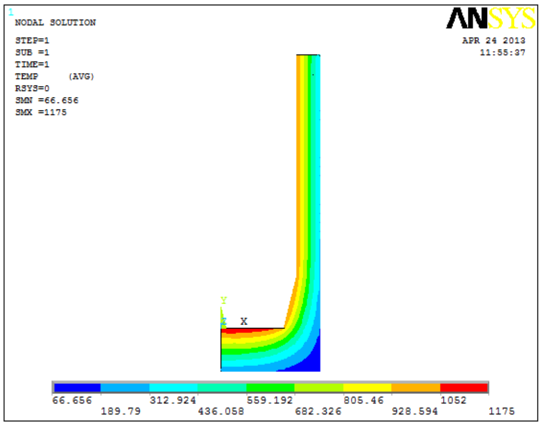
6. OPTIMIZATION OF GEOMETRICAL PARAMETER:

Induction heating is a complex electromagnetic and heat transfer process because of the temperature dependency of electromagnetic, electrical, and thermal properties of material as well as skin effect. The temperature profile of the heated work piece and the energy consumption are complicated functions and depend on characteristics of the power supply. So, it reduces with the optimum geometry of refractory material.

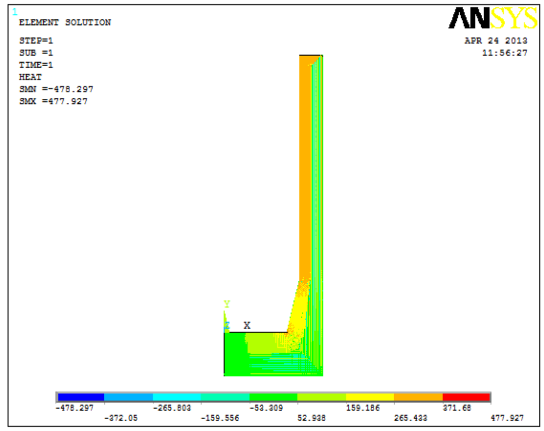
Table 6. Optimum geometrical parameter

Material	Ramming mass	Micasil	Coil core cement	Heat loss kWh	Temperature ^{0}C
Thickness in mm	165	3.5	10	757	66.70
	170	3.5	10	649	66.63
	175	3.5	10	478	66.67
	180	3.5	10	493	66.65
	185	3.5	10	506	65.30

Results with optimum geometry analyzed in APDL ANSYS software.



A. Temperature distribution curve



B. Heat flow

Optimization of geometrical parameter is effective to reduce the heat losses, and reduces 35% losses from furnace.

Total heat loss calculated with the optimum geometry is 477 kWh. So we have saved 260 kWh with 175 mm optimum thickness of the ramming mass.

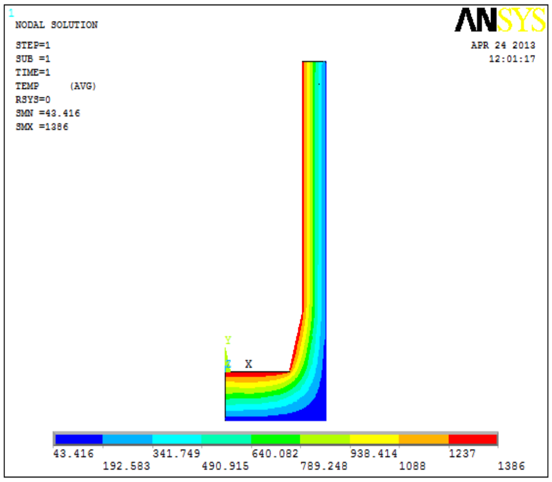
7. OPTIMIZATION OF MATERIAL PROPERTIES:

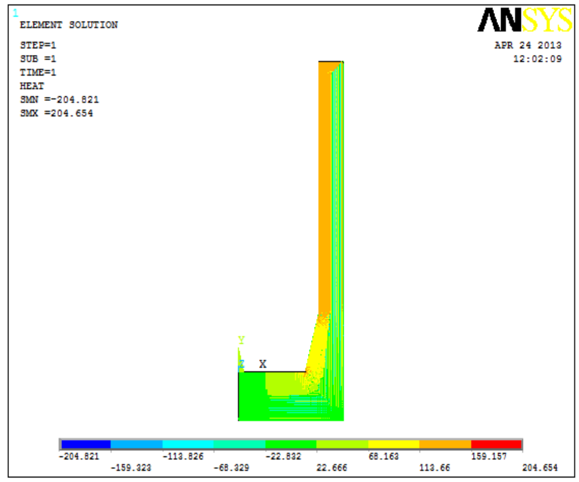
Optimization of the geometrical parameter is reducing heat losses up to certain limit, but this is not sufficient because of its huge losses.

Table 7 Optimum thermal properties

Material	Ramming mass	Micasil	Coil core cement	Heat loss kWh	Temperature ^0C
Thermal conductivity w/m ^0C	3	0.12	1.39	204	43
	3.5	0.12	1.39	226	44.12
	4	0.12	1.39	254	45.59
	4.5	0.12	1.39	273	46.56
	5	0.12	1.39	298	48.10
	5.5	0.12	1.39	316	49.15
	6	0.12	1.39	337	50.85

Analysis has done with material optimization of induction furnace. Following are the Optimum result with taking optimum properties drawn in table 7 and with the optimum geometry.





A. Temperature distribution B. Heat flow

This examination demonstrates that optimizing both the geometric parameters and material properties can contribute to the reduction of thermal losses and improvement in temperature distribution. By utilizing the optimal properties of the ramming mass, the total losses from the furnace amount to 204 kWh. Comparatively, properties optimization proves to be more effective than geometrical optimization in reducing heat losses from the furnace, resulting in a savings of 542 kWh. Ultimately, this approach allows for a reduction of 70% in losses.

Table 8. Result of optimum property and geometry

Material		Optimum Geometry	Optimum Properties
Ramming mass		175 mm	3 w/m ^{0}C
Micasil		3.5 mm	0.12 w/m ^{0}C
Coil core cement		10 mm	1.39 w/m ^{0}C
Heat flow		477 kWh	271 kWh
TFV sum	Nodal	69e3 kWh	31e3 kWh
	element	73.12 kWh	33.4e3 kWh

These conditions constitute the initial conditions of our simulation. After having fixed these parameters

8. RESULTS AND DISCUSSIONS

Following graph shows the effect of optimum geometry on heat losses and temperature distribution for induction furnace. Effect of increasing in thickness of

ISSN: 2394-3696, Website: www.ijiert.org, July, 2023

refractory material is reduced heat losses and temperature distribution with 175mm thickness. Following graph shows its behavior against thickness fig 2.

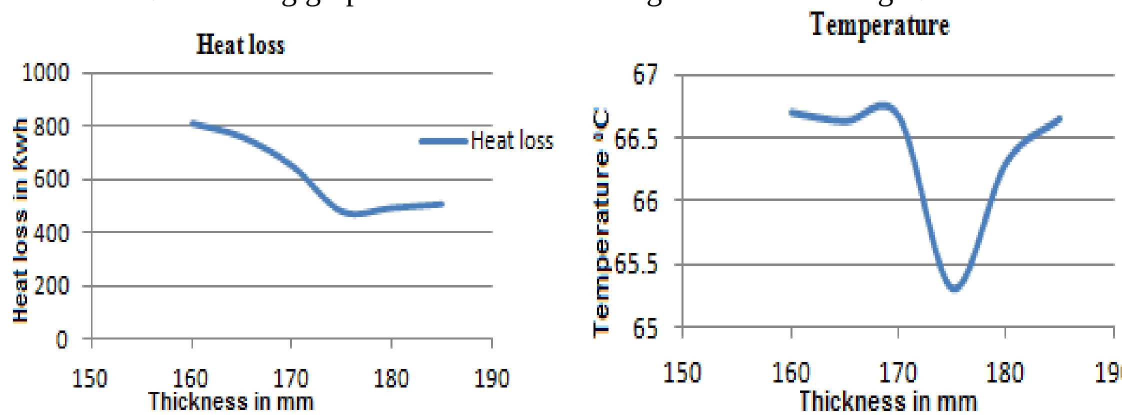


Fig 2. Heat loss and temperature distribution profile for optimum thickness of refractory

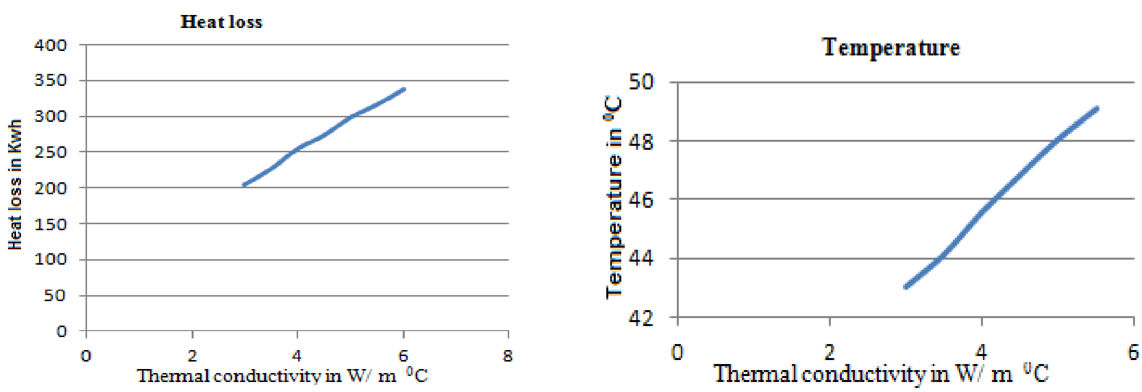


Fig 3. Heat loss and temperature distribution profile for optimum properties of refractory

The accompanying graph illustrates the impact of optimal material properties on heat losses and temperature distribution in an induction furnace. The ideal thermal conductivity significantly influences the reduction of losses and leads to a decrease in temperature distribution. The increase in thermal conductivity directly affects the temperature and losses experienced by the furnace, emphasizing the importance of minimizing it. Figure 3 portrays the relationship between thermal conductivity, losses, and temperature distribution within the furnace.

9. CONCLUSION

In this paper, the paper presents an examination of the stationary thermal behavior of the induction furnace. The optimization plays a crucial role in diminishing losses and offering a favorable temperature distribution profile.

The findings of the analysis reveal a decrease in the temperature field and heat flow during the melting process. The sum of the thermal flux vector at the nodal and element levels of the furnace increases.

Based on the obtained results, it can be concluded that they align with the findings commonly reported in the literature. It would be intriguing to employ Ansys software for resolving the static thermal analysis problem. It is necessary to validate the analytical calculations with the results obtained from the software.

Therefore, according to the aforementioned results, a 73% reduction in losses can be achieved through properties optimization and a 35% reduction through geometrical optimization. Ultimately, by attaining optimal geometry and properties of the ramming mass, total losses can be reduced by 70% while considering the optimum thickness and material properties of the induction furnace.

REFERENCES

1. Prof. N. C. Mehta, Mr. Akash D. Raiyani, Vikas R. Gondalia“ Thermal Fatigue Analysis of Induction Melting Furnace Wall for silica ramming mass”, International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 2, February 2013).
2. Laszlo Koller, Balazs Novak, “Ridged surface for reducing eddy-current losses in ferromagnetic shielding”, Electr Eng (2009) 91:117–124, DOI 10.1007/s00202-009-0124-z.
3. K. C. Bala, “Design Analysis of an Electric Induction Furnace for Melting Aluminum Scrap” Mechanical Engineering Department, Federal University of Technology Minna, Niger State, Nigeria AU J.T. 9(2): 83-88 (Oct. 2005).
4. Hong-Seok Park and Xuan-Phuong Dang, “Optimization of the In-line Induction Heating Process for Hot Forging in Terms of Saving Operating Energy” International journal of precision engineering and manufacturing vol. 13, no. 7, pp. 1085-1093

5. M. M. Ahmed, M. Masoud and A. M. El-Sharkawy, "design of a coreless induction furnace for melting iron" international conference on communication, computer and power (icccp'09) muscat, february 15-18, 2009.
6. Kalinchak, V. I. Sadkovskii, and S. G. Orlovskaya, "Influence of internal response on the critical conditions of heat and mass transfer of carbon particles" Journal of Engineering Physics and Thermophysics, Vol. 71, No. 5,1998.