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Investigating Heat Loss Prevention in Vacuum Furnace Walls: The Role of Metal Coating and Air Gap Thermal Analysis

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Abstract: Metal melting is most often done in furnaces. Induction furnaces are more effective since no fuel is utilized. discovering life in induction-thermal conditions The furnace wall is an issue. One form of composite material is used to make the induction wall of furnaces. Heat loss and furnace wall fracture are caused by cyclical thermal stresses. This study focused on finding the best way to avoid heat loss via an induction furnace's walls in order to achieve the lowest heat losses. The current study illustrates how a vacuum void in the furnace wall is affected by the insulation's thickness. A current furnace has been constructed for insulation thickness using modeling tests with Ansys. The wall furnace uses three materials: molybdenum, graphite, and stainless steel. Ansys Workbench programming is the subject of this study, and the findings are being taken into consideration. Based on the physical specification of its failure under thermal circumstances, the temperature conveyance and thermal stress distribution fields of the refractory furnace induction wall were calculated using ANSYS finite part test programming.

Keywords: Furnace wall, Thermal analysis, Heat losses, Composite material, Ansys.

I. Introduction

An induction furnace is a specialized electrically operated device designed to heat and melt metals. It represents a broader category of furnaces, which are enclosed spaces where heat is applied to increase the temperature of an object. In industrial settings, induction heating plays a pivotal role in processes like solidifying metal and preheating for various production tasks.

The primary benefit of induction furnaces is their efficiency. They prioritize minimal electrical power loss and emphasize environmental protection by reducing heat waste. Unlike traditional furnaces, an induction furnace doesn't rely on fuel. Instead, it heats through a conductive method, where the furnace surrounds a crucible placed inside a water-cooled alternating current solenoid coil. This innovative approach to melting makes induction furnaces energy-efficient and easily controllable, offering advantages over many traditional metal melting techniques. In recent times, numerous foundries have adopted this technology, with some even replacing older methods like cupolas, especially when melting cast iron. This shift is primarily due to concerns over contaminants and waste produced by older furnace designs. However, induction furnaces are not without challenges. Heat loss through heat transfer is common, emphasizing the need to optimize composite materials used in the furnace, study their thermal conductivity, and determine the ideal wall thickness of these materials. These furnaces present an ongoing research challenge, blending various material science domains whose interrelationships are not yet fully understood. Globally, researchers are contributing to this field, developing unique simulation methodologies and corroborating their findings through meticulous experimentation.

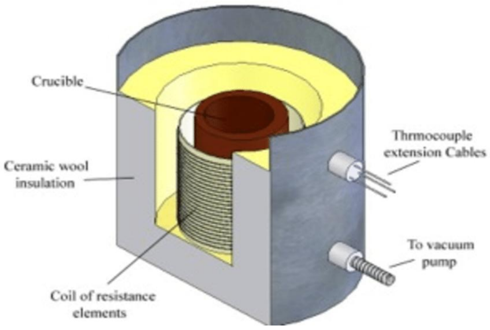

Figure 1: Vacuum Furnace [10]

II. Heat Losses in Furnaces

The primary objective of this work is to examine thermal conductivity and wall thickness of induction heater wall material during dissolution of metal with the least thermal losses. Section 1 indicates the related region in furnace for thermal losses.

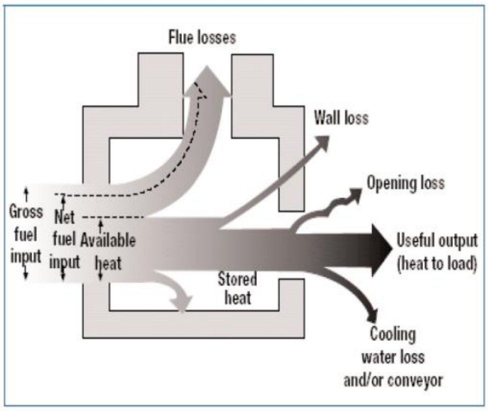

Figure 2:Modes of heat losses [6]

III. Finite Element Analysis (FEA)

The Finite Element technique is a computational approach to simplify an integral or differential condition. It has been related to numerous physical disorders, where unequal requirements of supervision are available. The technique basically consists of waiting for the piecewise compatible arrangement potential and making the capability parameters in a way that reduces the arrangement error. Numerous physical processes can be represented as well as partly differential situations in architecture and physics. In general, it is practically difficult to reduce these requirements by conventional logical methods for self-assertive types. The finite element method (FEM) is a computational technique that allows these PDEs to be partially settled by. The FEM is a capability / premise-based approach to approaching PDE comprehension. FE is commonly used in various fields for solving static and dynamic problems − solid or liquid mechanics, electromagnetics, biomechanics, and so on. The Finite Element method (FEM) uses discrete components to obtain the approximate differential state supervisory scheme. The last condition of the FEM system is constructed from the discrete conditions of the modules. FEM relies on the probability that the structure condition may be separated into minimal components and component conditions used to represent the integrated components in the first method.

IV. Design and Analysis of Furnace Wall

Furnace wall templates designed with the range of material from Stainless steel, graphite and molybdenum materials used to produce four layers of insulation coating here. The realistic application of modelling finite elements is known as FEA which is better understood during the actual problem-solving process. FEA was commonly used by the car industry. It is an extremely prominent tool in the product development strategy for the design builds. To make FEA an efficient modelling method, it is important to grasp the FEA fundamentals and design methodology, explain processes, the underlying flaws and their impacts on the essence of the outcomes. FEA is also used as a statistical method for the study of engineering problems.

a. *Geometry and Experimental Setup*

Furnace wall sample designed in Ansys for optimizing minimum heat losses by applying material for coating on wall inside and provided vacuum gap between materials to reduce heat losses.Experimentation for evaluation of temperature distribution was performed on a vacuum resistance furnace capable of reaching a temperature of 1500 ◦C and a vacuum of 10−4 Pa. The hot zone of the furnace was made of Molybdenum and the insulation system was made of graphite blanket. The support structure of the furnace was made of stainless steel with the outer vessel also made of stainless steel.

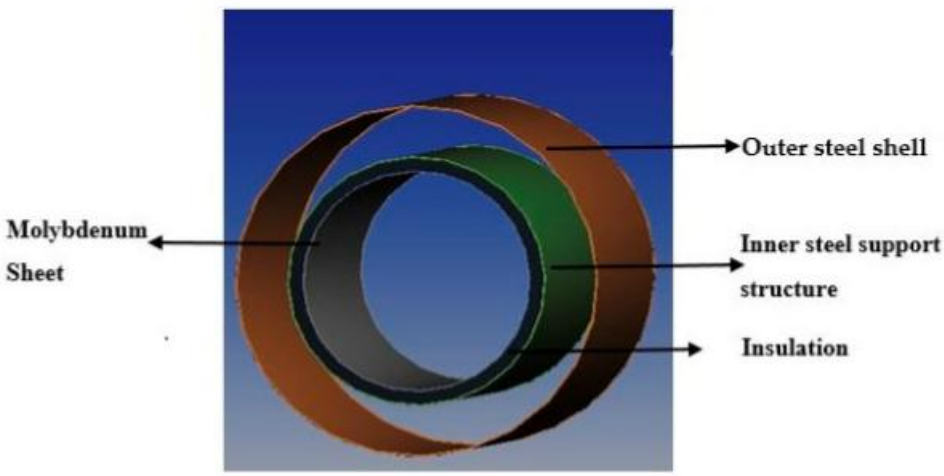

Figure 3: Cylindrical wall of vacuum furnace with air gap used in furnace

b. *Applying boundary conditions*

Following the design of the furnace wall model, the applied air convection temperature is 22 °C, and the inner layer is chosen to apply a working temperature of 1000 °C to test the maximum and lowest heat transfer rates as well as thermal stresses. We meshed with coarse, medium, and fine configurations of element size and discovered that medium and fine meshing produces results that are roughly correct. As a result, we decided to use a medium mesh density of 0.1 m to cut down on calculation time and expense. In the first analytic setup, the ambient temperature was set at 22 0C, and additional boundary conditions are shown in Figure 4. The furnace's internal temperature was set at 1000 0C, which corresponds to the real process temperature. Due to the vacuum within the furnace, it was expected that convection would be low, and radiation was modeled using the surface-to-surface technique. This technique is utilized primarily when a thermal system lacks a participating medium.

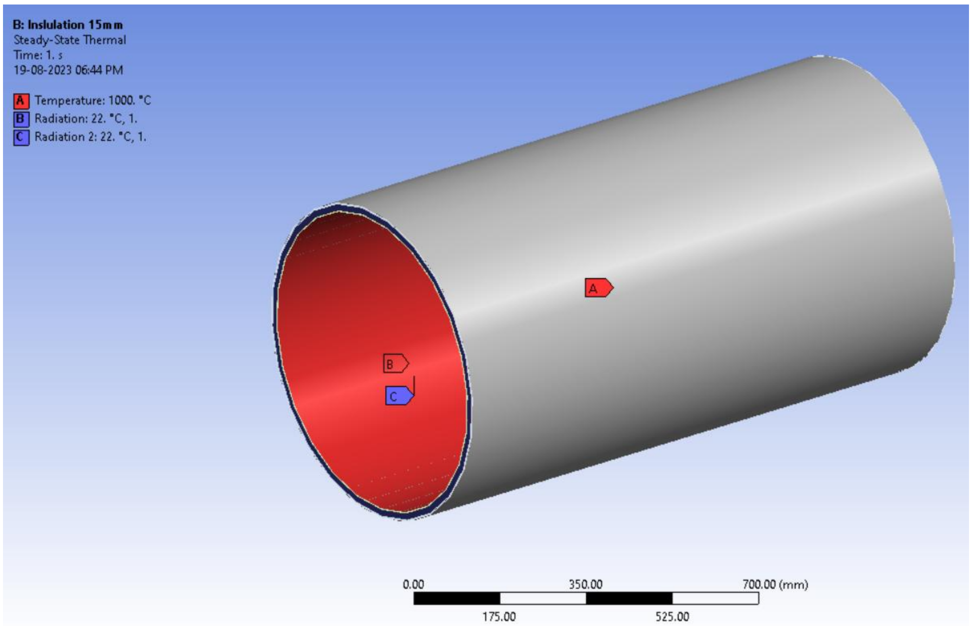

Figure 4: Applying Boundary conditions of Furnace wall in Ansys

In this study Three types of materials i.e. Stainless steel, graphite and molybdenum materials are used for analysing minimum heat losses in furnace by using composite material in furnace wall. Properties of materials are described below in table 1.

Table1: Material propertiesused in designing model

Properties	**Material Description**		
	Molybdenum	**Graphite**	**Stainless steel**
Thermal Conductivity (W/mK)	112	0.46	13.8
Emissivity	0.82	0.97	0.66
Density (g/cm^3)	10.28	1.8	8

V. Results and Discussion

Thermal analysis of furnace wall cylinder with thickness variations we found temperature difference to minimization of heat losses. Figure shows the temperature variation of design model in Ansys.

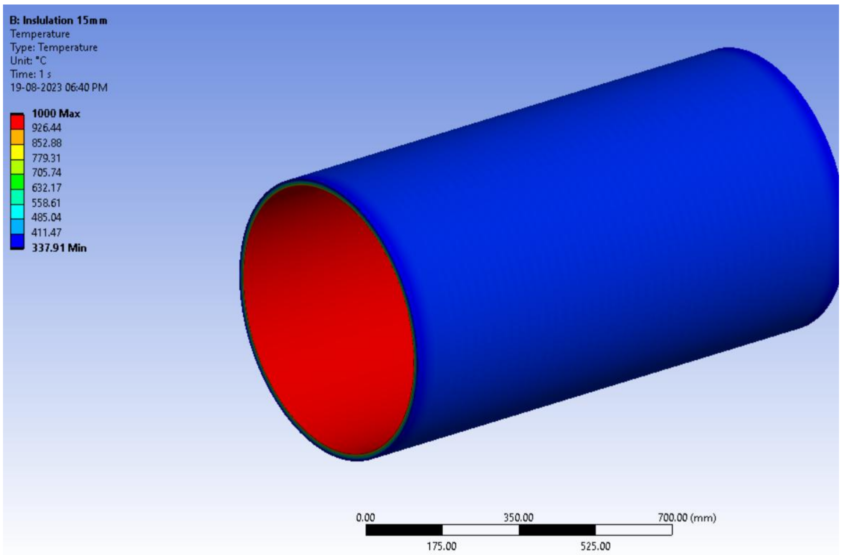

Figure 5: Temperature variations at 15mm thickness

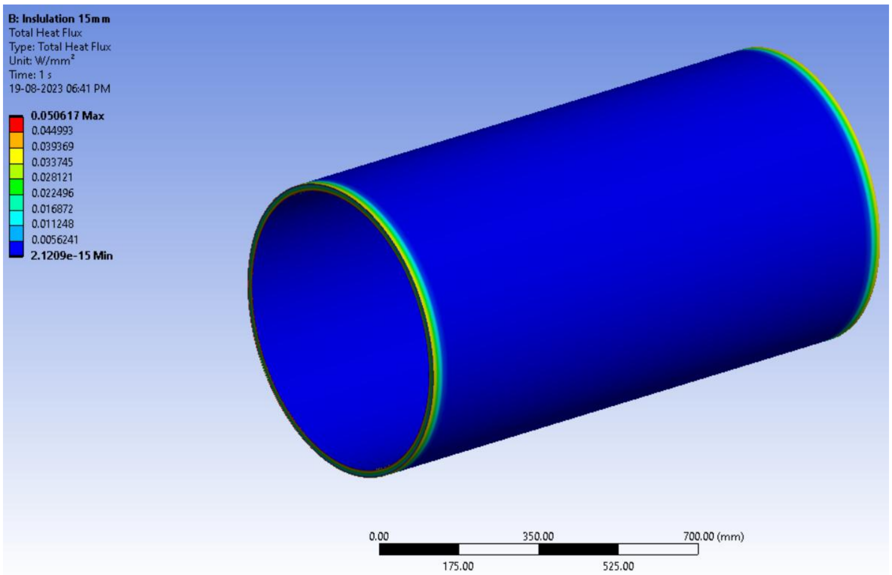

Figure 6: Total Heat Flux variations at 15mm thickness

As per above figure, inner side of vacuum furnace we apply 1000 ^{0}C temperature inner side material coating is molybdenum material, outer side material coating is graphite material. After analysis found minimum temperature of inner molybdenum surface temperature is 337.91 ^{0}C.

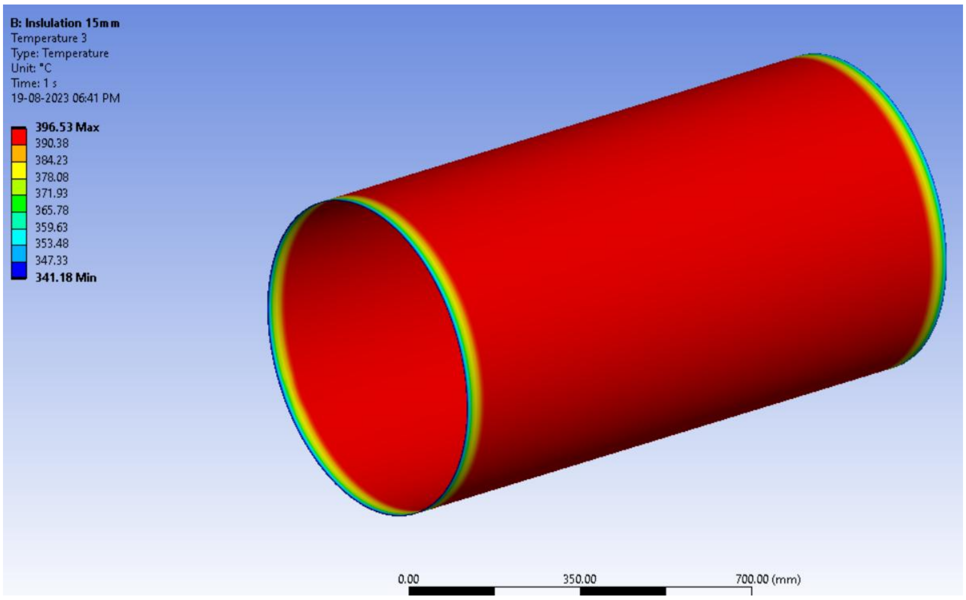

Figure7: Outer shell temperature at 15mm thickness

As per Thermal analysis of Furnace wall with various material coating on outer layer of inner cylinder. After that thickness varies from 15mm, 25mm, 35mm, 45mm, 55mm, and 65mm. than optimized its behaviour by finding temperature drop in model to minimization of heat losses.

Table 2: Thermal Analysis Results of temperature variations in furnace cylinder wall

Insulation Thickness(mm)	**Minimum Temperature**	**Total heat flux**	**Temperature drop**	**Outer core Temperature**
15	337.91	0.0506	662.09	396.53
25	262.77	0.0415	737.23	266.43
35	214.9	0.0418	785.1	215.32
45	182.82	0.039	817.18	182.82
55	155.02	0.0373	844.98	155.27
65	137.9	0.0359	862.1	137.9

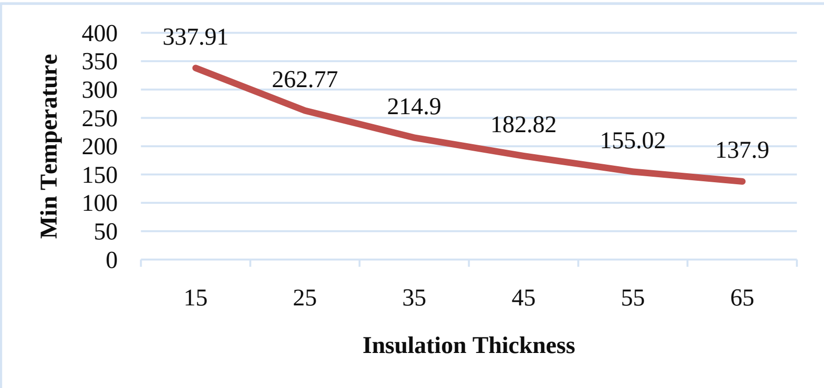

Figure8: Temperature variation with various insulation thickness

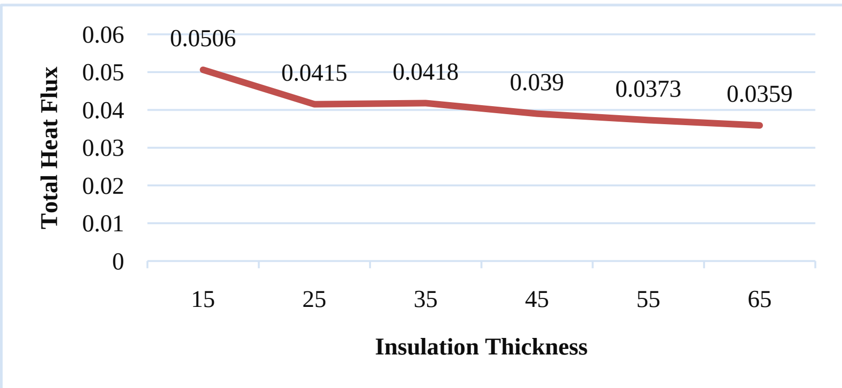

Figure 9: Total Heat Flux with various insulation thickness

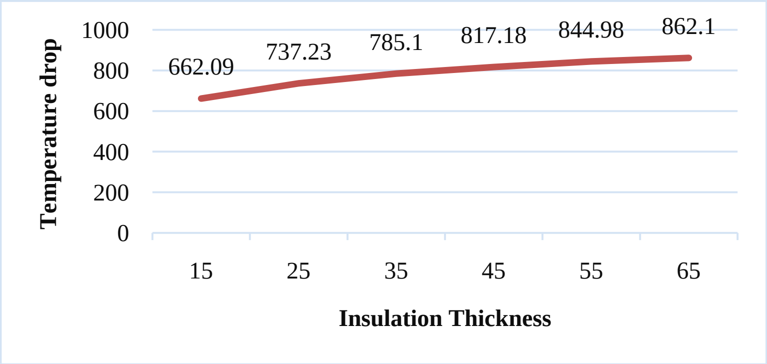

Figure10: Temperature drop with various insulation thickness

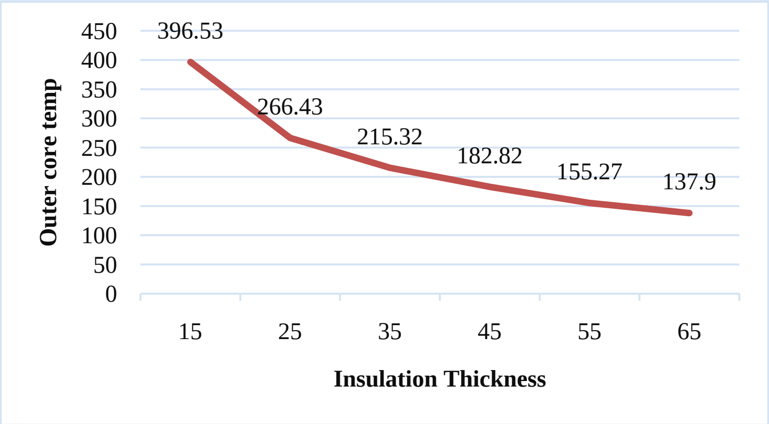

Figure11: Outer core temperature with insulation thickness

We performed simulation analysis of furnace wall insulated by material coating and optimized temperature variations as per Nodes varies.

Table:1Thermal variations in furnace wall Temperature as per Nodes

No. of Nodes	**Min Temp**	**Total heat flux**	**Temp drop**	**Outer core Temp**
1.70E+05	337.91	0.0506	662.09	396.53
1.49E+05	342.41	0.0546	657.59	397.71
2.67E+05	341.2	0.0546	658.8	397.71
5.05E+05	341.84	0.059	658.16	396.78
1.14E+06	341.78	0.061	658.22	396.43

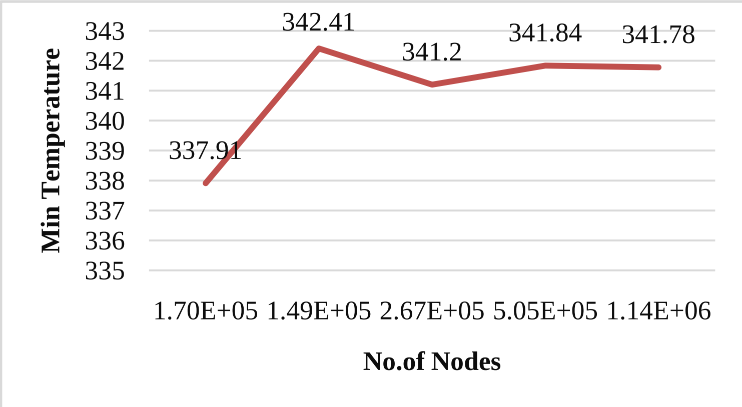

Figure12: Minimum temperature due to Node variation

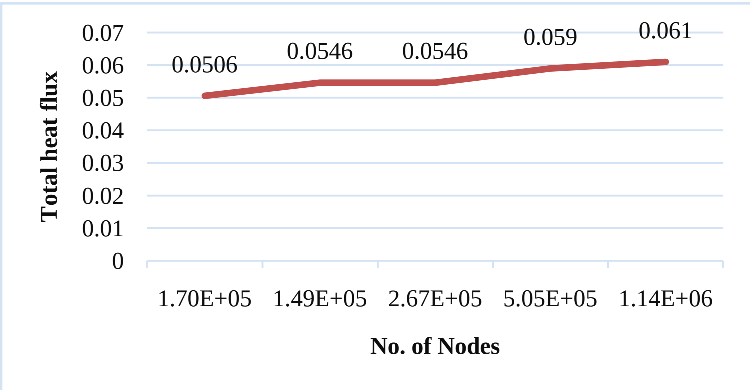

Figure13: Total Heat Flux due to Node variation

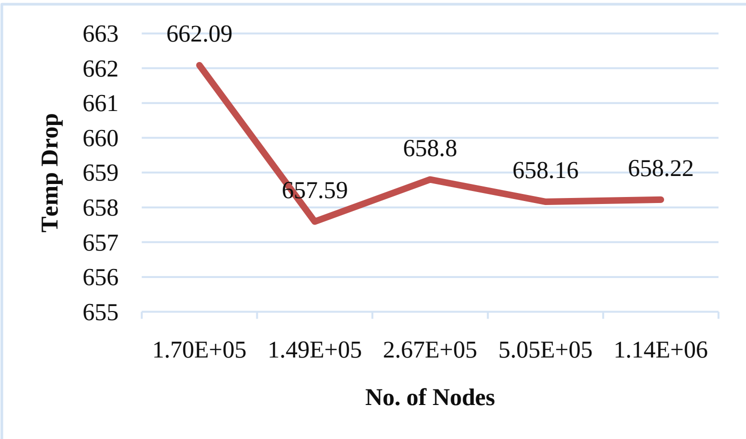

Figure 14: Temperature drop due to Node variation

As per above study, the vacuum resistance furnace was optimized for heat loss using experimental data. The experimentation was performed to evaluate the boundary conditions of designed model. On the basis of the ANSYS results, insulation thickness was increased to maximum available space inside the structural shell of the furnace.

VI. Conclusion

According to the aforementioned research, it is determined that in order to reduce heat loss, three different materials—molybdenum, graphite, and stainless steel—were employed for the steady state thermal analysis of the vacuum furnace wall for variable thermal conductivity. Molybdenum and graphite coatings were added to the inner and outer cores, respectively. The composite material provides an excellent temperature circulation outline and is crucial in reducing heat losses. The analysis's findings indicate that when the thermal conductivity of the wall material falls, so does the heat flow during melting. Therefore, I have discovered and verified the furnace model's ideal thermal behavior when created from composite material compositions.

- According to the findings of ANSYS' steady state thermal study, the inner core's maximum temperature reduces to 337.91 °C from 1000 °C.
- Heat flux measured at 15mm wall thickness was 0.0506 W/mm^2. Heat flux reduces as thickness rises.
- The minimum temperature drop was discovered on a wall thickness of 15 mm, which was 662.09 °C, while the largest temperature drop was obtained on a furnace wall thickness of 65 mm.
- As a consequence of the data, we can conclude that increasing thickness with a coating of metallic material reduces heat losses in furnaces, with the maximum temperature of the outside surface found at 15 mm thickness and the lowest temperature found at 65 mm thickness.

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