Optimization of the Composite Insulating Wall Thickness of Induction Furnace through ANSYS Simulation

Shine George,

Lecturer in
Automobile Engineering
Technical Education Department, Kerala
Government Polytechnic College, Kalamassery, India

Abstract— **This paper aims to investigate the heat transfer characteristics of composite wall of the induction furnace and its thermal fatigue life. The main objective of this research is to determine accurately the heat loss through the cylindrical wall which can be eliminated to a greater extent by properly selecting the ramming mass thickness. Also an investigation is to be carried out to ascertain the effect of thermal stress on the furnace lining life. Hence this research is aimed at minimizing the heat loss as well as maximizing furnace lining life. Measured dimensions and temperatures of the existing furnace were used to create a virtual model in ANSYS and the optimization was done.**

Index Terms— Induction furnace, Composite insulating wall, Fatigue Life, Ramming mass thickness.

I. INTRODUCTION

Induction furnaces are popularly employed by cast iron making industries due to their highly efficient, pure, homogeneous stirring and easily maneuverable nature compared to other types of furnaces, see Inductotherm [1] The induction furnaces have always played a significant role in electric power consumption in foundry and hence the intake of minimum electric power and environment protection have become imperative in the case of furnaces according to Patange and Khond [2]. There is always a substantial amount heat loss through the lining of an induction furnace. So the heat transfer characteristics of a furnace lining have great importance in the furnace operating cost. In a coreless furnace, the refractory-lined crucible is completely surrounded by a water-cooled copper induction coil, see Inductotherm [1]. Current flowing in one direction in the induction coil induces a current flow in the opposite direction in the metal charge. In order to keep the molten metal at pouring temperature, electrical energy consumed should be equal to the amount of heat loss. So the furnace is to be insulated to ensure minimum heat loss from it and the thickness of the insulating wall is our subject matter of relevance.

The steady state thermal investigation of induction furnace with alumina ramming mass by Mehta et al. [3] revealed that there exists an optimum thickness for the present furnace of their analysis and that will reduce the total heat loss by about 15%.

Mehta et al [4] have conducted a thermal fatigue analysis of an induction furnace wall by FEM. A furnace is always subjected to large temperature variations especially during emptying of molten metal in to the ladle. Due to this the working wall is subjected to fatigue failure and hence a new lining is to be done between 200 to 400 hours of life time.

Wei [5] has done an experiment the effect of thickness on the fatigue life of ceramic discs. The results indicate that a critical factor in the thermal shock performance is thickness.

The study conducted by Kukartsev et al [6], it has been found that, the quantitative content of different phases in the quartzite can play a crucial role in determining the heat capacity and durability of the lining in a furnace. Understanding the composition of the quartzite and its thermal properties can help in selecting the appropriate lining material and optimizing furnace operation to minimize damage and extend the life of the lining.

Muratovich et a l[7] have proved that the chemical composition of the alloy being produced, the temperature of the melt, the chemical composition of the lining material, and the porosity of the refractory material are all important factors that can affect the degree of destruction of the lining in a furnace.

Mehta et al [8] have found that the modified S-log N curves can be used to represent the relationship between the applied stress range and the number of cycles to failure for a specific material. These curves are modified to incorporate the effects of temperature and other boundary conditions to better predict the fatigue life of ceramic-based refractories.

Testing and experimentation by Cui K et al [9] proved that addition of carbide materials to carbon composite bricks used refractory linings, in can help to improve their thermal conductivity, which can help to dissipate heat more effectively and reduce the risk of thermal shock. Additionally, carbide materials are often highly resistant to corrosion, which can help to protect the bricks from damage caused by contact with molten iron, slag, and other harmful elements.

From the above studies it can be concluded that the thermal fatigue life of a cylindrical specimen depends on many factors such as composition of both refractory lining and melt, temperature and the variation in temperature of the melt. Also it is inversely proportional to its thickness of the ramming mass. But if we go for a smaller thickness the heat loss by conduction increases. So in order to have an optimum thickness we must make a trade-off between heat loss and fatigue life.

II. EXPERIMENTATION OF HEAT LOSS

The following Fig. 1 of the existing induction furnace was based on the drawings provided by Inductotherm Company.

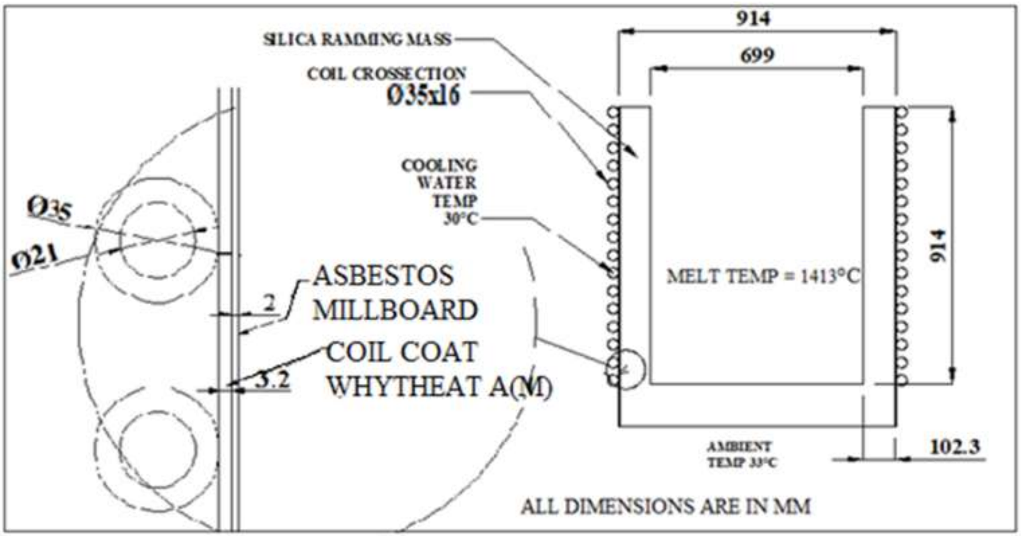

Fig. 1. Drawing of the Existing Furnace

The measurements of furnace and the properties of material of the furnace are tabulated as in Table 2 and temperature distribution is in Table 3.

Table 2. Dimensions and properties of existing furnace

Material	Dimensions in mm		Thermal Properties	Units
	Inner Diameter	Thickness		
Copper coil	914	7	Conductivity, K =400	W/m K
			Film coefficient between Cu - Water h_{cw} =1000	W/m^2 K
Coil Coat (WhytheatAM)	907.6	3.2	Conductivity, K =1.2784	W/m K
Asbestos millboard	903.6	2	Conductivity, K =0.1214	W/m K
Ramming mass (TRL Ram SK 165)	699	102.3	Conductivity, K =5	W/m K
			Film coefficient between melt - wall h_{m-w} =200	W/m^2 K
			Film coefficient between melt - air h_{m-a} =30	W/m^2 K

Table 3. Temperature distribution in existing induction furnace

Notation	Content	Temperature °C
Ti	Inner temperature (Melt)	1413
To	Ambient temperature	33
Twi	Coil Inlet temperature of water	28
Two	Coil Outlet temperature of water	30

In order to keep the melt at a pouring temperature of 1413^{0}C, electrical energy was continuously consumed equal to the amount of heat loss. Table 4 shows the calculated heat loss and temperature distribution.

Net energy consumption in one hour = 150 kWh

Table 4. Calculated Heat loss and Temperature Distribution

Heat loss calculated (kWh)				**Temperature in ^{0}C**						
Conduction	Convection	Radiation	Total	T_i	At the interfaces of composites walls				Cu Tube inner wall, T_{cw}	T_{wo}
					T_1	T_2	T_3	T_4		
72.38	15.89	50.92	139.19	1413	1232.7	585.51	126.93	57.65	57.17	30

Table 5 Comparison of Analytical and Software values for Validation.

Method	Temperature in ^{0}C					Conduction loss(kWh)
	T_1	T_2	T_3	T_4	T_{cw}	
Calculated/ Analytical Value	1232.69	585.51	126.9	57.65	57.17	72.38
Software Value	1239.5	564.68	123.3	56.61	56.15	69.66

The calculated (139.19 kWh) and actual values (150 kWh) obtained were nearly same. A virtual model was prepared based on the conduction loss and temperatures at various points of the composite wall

I. HEAT LOSS SIMULATION BY ANSYS

Here the existing furnace model was virtually created using ANSYS steady state thermal module as in Fig. 2.

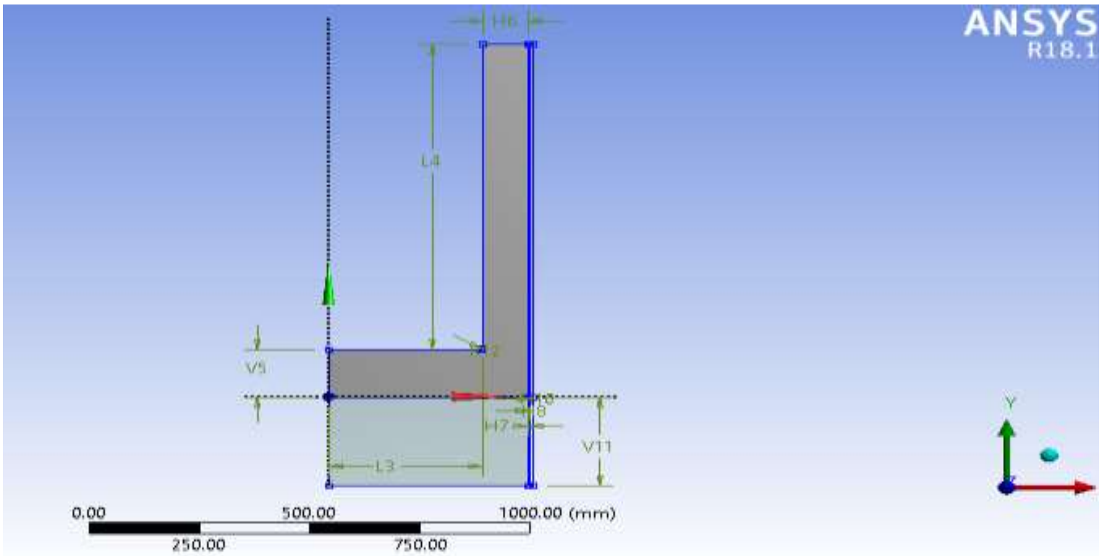

Fig 2 Surface model of the furnace

Since the model was axisymmetric about Y – axis we needed only a cross section or 2D model or surface model of the furnace for validation and optimization. In order to have better accuracy here we used equiangular quad node for meshing with a total of 12922 elements and 39467 nodes. The temperature and heat flux curves obtained are as shown Fig. 3 and Fig. 4 respectively.

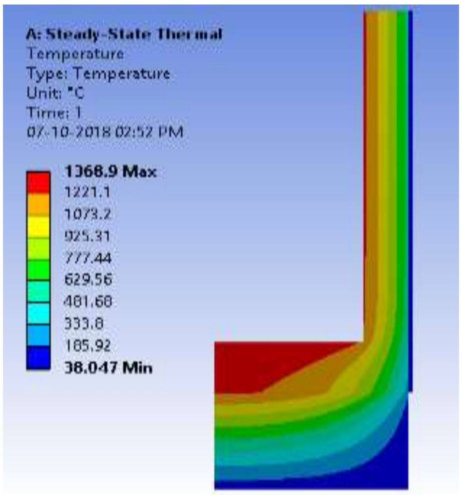

Fig 3. Temperature Curve

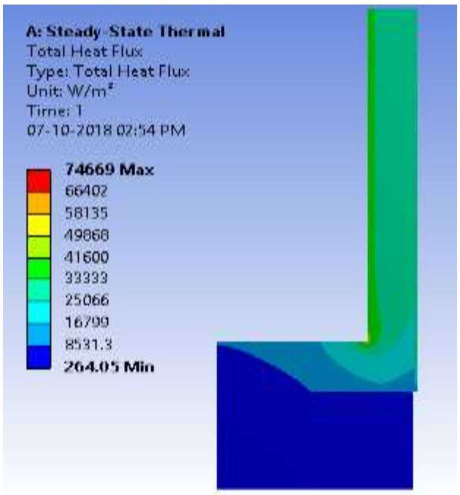

Fig 4. Total Heat Flux Curve

Optimization means, making the best or most effective value of a given dimension. Here it is required to find the value of thickness of ramming mass which give a minimum value of heat loss. The variation in heat loss with thickness is as shown below in Fig. 5.

Fig. 5 Variation of Heat Loss with Thickness

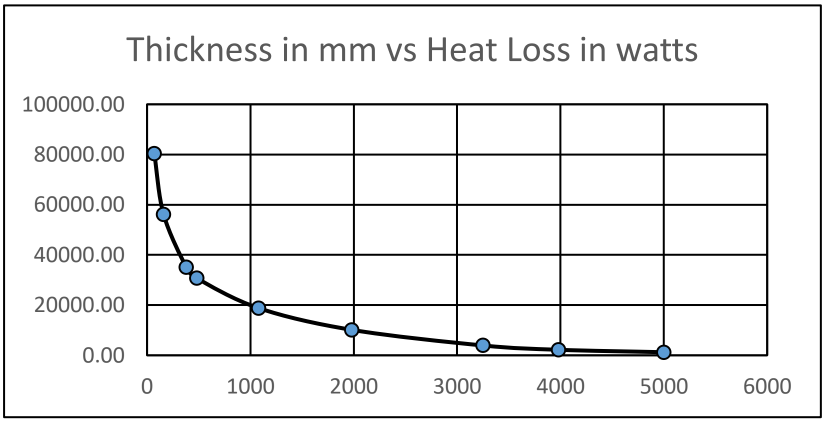

Fig. 6 shows the variation in fatigue life with thickness

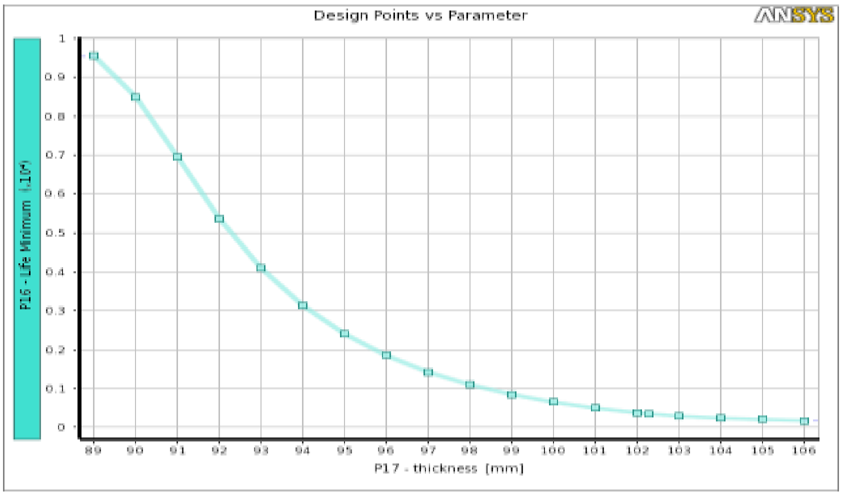

Fig. 6 Variation in Fatigue Life with Thickness

Fig. 7 shows this variation in Total cost, between thicknesses 89 mm and 96 mm So it is clear from the results that there is an optimum thickness of 93 mm for the silica lining, which can reduce the total cost than the existing lining with thickness of 102.3 mm by about 11%.

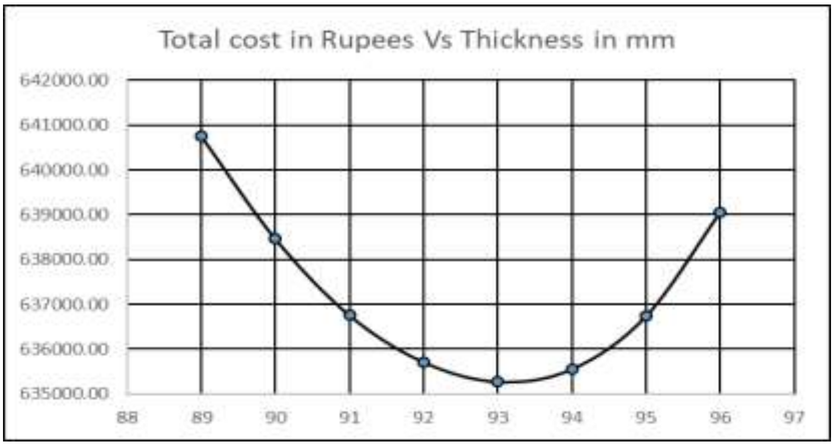

Fig. 7 Variation in Total Cost with Thickness - (89 mm -96 mm)

III. CONCLUSIONS

1. It has been found heat loss approaches zero when the thickness is very large and also, there is no such optimum value of thickness, beyond which the heat loss will increase.
2. A thicker lining increases the inside temperature which is desirable, but on the other hand it will increase both thermal stress and strain on the lining wall.
3. An increase in thickness of the lining will increase the resistance to heat loss but at the same time will cause a reduction fatigue life hence an optimum thickness is a tradeoff between heat loss and total cost of furnace lining.

REFERENCES

[1] Inductotherm (India) Pvt.Ltd - Training Wing.: Customers Engineer Training Manual Section I, pp. IN/15, Section II, pp. IP/3, pp.WS/01- WS/09, Ahmedabad; 1998.

[2] Patange G., Khond M., Some studies on energy consumptions and identification of suitable energy management techniques in Indian foundry industries. European Scientific Journal, ESJ. 2013;9(24).

[3] Mehta N.C., Shukla D.D., Popat R.K., Optimisation of Wall Thickness for Minimum Heat Loss for Induction Furnace by FEA. Indian Foundry Journal. 2014;60(12):19–25.

[4] Mehta N., Raiyani A., Gondalia V., Thermal fatigue analysis of induction melting furnace wall for silica ramming mass. International Journal of Emerging Technology and Advanced Engineering. 2013;3(2):357–362.

[5] Wei GC. Hot Gas Method and Apparatus for Thermal Shock Testing. Thermal Shock and Thermal Fatigue Behavior of Advanced Ceramics. 1993;483–494.

[6] Kukartsev VA, Kukartsev VV, Tynchenko VS, Kurashkin SO, Sergienko RB, Tynchenko SV, Panfilov IA, Eremeeva SV, Panfilova TA. Study of the Influence of the Thermal Capacity of the Lining of Acid Melting Furnaces on Their Efficiency. Metals. 2023 Feb 8;13(2):337.
[7] Muratovich TT, Kayumjonovich TN, Pirmukhamedovich AS, Teleubaevich Ut. Selection Of The Material Of The Lining Of Induction Furnaces In Steel 20gl. Web of Scientist: International Scientific Research Journal. 2022 May 31;3(5):1728-39.
[8] Mehta, Nirajkumar, and Dipesh Shukla., Comparison Of Thermal Fatigue Behaviour Of Silica And Alumina For Induction Furnace Wall. International Journal Of Advance Research And Innovative Ideas In Education ·, ISSN(O)-2395-4396, Vol-7 Issue-2 2021, March 2021
[9] Cui K, Wang J, Wang H, Zhang Y, Fu T. Erosion Behavior and Longevity Technologies of Refractory Linings in Blast Furnaces for Ironmaking: A Review. steel research international. 2022 Nov;93(11):2200266.