HEAT TRANSFER ANALYSIS OF BLAST FURNACE REFRACTORY LINING

A thesis Submitted in partial fulfillment of the requirements for the award of the degree of

Master of Technology

in

Mechanical Engineering

(Thermal Engineering)

By

Ajoy Kumar Nandy

212ME3315

Department of Mechanical Engineering
National Institute of Technology Rourkela
Odisha-769008, India

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Under the guidance of

Prof. S. K. Sahoo

Department of Mechanical Engineering
National Institute of Technology Rourkela
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DEDICATED

TO

MY PARENTS

National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "**HEAT TRANSFER ANALYSIS OF BLAST FURNACE REFRACTORY LINING**" submitted by **Mr. Ajoy Kumar Nandy** in partial fulfillment of the requirements for the award of Master of Technology Degree in **Mechanical Engineering** with specialization in **Thermal Engineering** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Prof. S. K. Sahoo
Department of Mechanical Engineering
National Institute of Technology
Rourkela
Rourkela– 769008

ABSTRACT

This paper gives a systemic study and review of blast furnace cooling stave with refractory lining materials used in the metallurgical industries based on heat transfer analysis. The three dimensional model of heat transfer of cooling stave with refractory lining in a blast furnace are modelled and analyzed with the help of ANSYS software. The model further utilized for the heat transfer analysis of different thickness of lining materials. The Refractory lining material which is used in this experiment are mullite bricks (65%Al_2O_3&35%SiO_2) with different stave materials (copper, aluminium and cast iron). We have identified a stave cooler in RSP(Rourkela steel plant) blast furnace -4 in Bosh zone where heat load is maximum for our experiment purpose. The data collected from RSP is used for developing a 3 D model of heat transfer analysis of refractory lining with stave cooling. We collected the heat flux data of subjected stave cooler and tabulated for our experimental study. The experiment result collaborates with the actual result developed in the 3D model. Further, In this study refractory lining thickness of the blast furnace is taken as 650mm from the inner side of the furnace to the stave body by gradually decreasing the refractory lining thickness up to 550mm. Copper and aluminum is used in place of cast iron as stave material, the factor of safety of the stave material is greatly enhanced due to higher thermal conductivity.

***Keywords*:** Heat transfer, Refractory linings, Cooling stave.

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PLACE: **Rourkela**

AJOY KUMAR NANDY

212ME3315

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

K = Thermal Conductivity of material, (W/mK)

C_p= Specific heat of fluid, J/kgK

L = Total length of stave, m

A = Area of stave, m2

m = Mass flow rate, (Kg/s)

q" = Heat flux experienced at hot face of stave, (W/m^2)

Q = Heat extracted by the stave, (W)

dT = Temperature difference (K)

Re = Reynolds number

D = Diameter of cooling pipe, (m)

Greek symbols

μ = Dynamic viscosity, (Ns/m^2)

ρ = Density of fluid and solid, (kg/m^2)

υ = Kinematic viscosity, (m^2/s)

CHAPTER 1
INTRODUCTION

1. **INTRODUCTION**

In consideration of the vast capital investment required for blast furnace relining, great efforts have been made to extend the campaign life of blast furnaces. Lining is the most important factor for determining the campaign life of a blast furnace. The cooling of refractory lining is the most contributing factor in deciding the Furnace campaign life. Lining cooling by stave technology is one of the products of such efforts. A stave is a cooling device having one or more internal channel, and is installed in numbers on the inner surface of a blast furnace to protect its steel shell and maintain the inner profile. The staves were made conventionally of cast iron. But now days copper staves are used in place of cast iron staves, which is excellent in heat conductivity. Water is used as a medium for transfer of excess heat from inside the furnace to keep the lining cooled & prevent it from faster wearing out. Figure 1 indicates arrangement of stave cooler in a blast furnace for lining cooling.

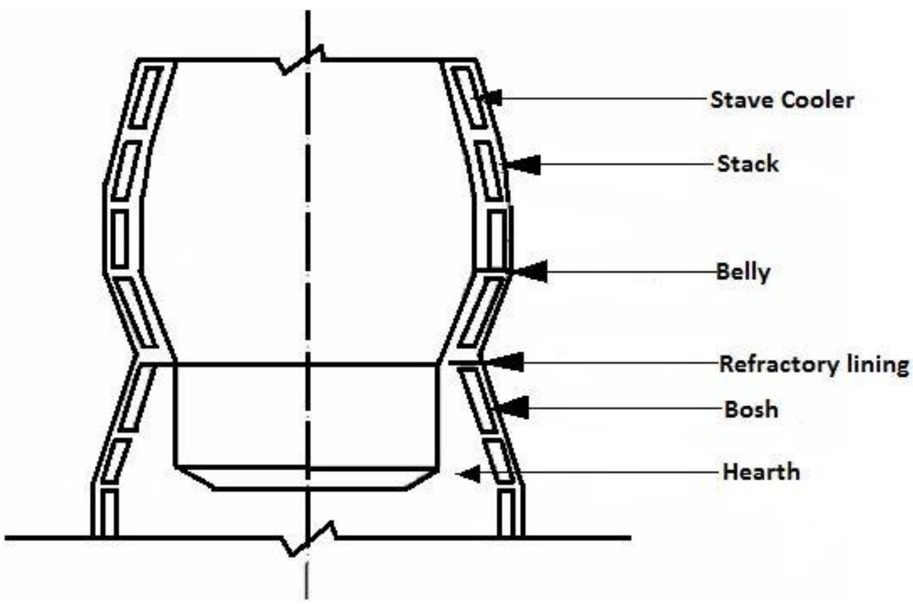


Figure 1.1 Arrangement of stave coolers in a Blast Furnace

1.1 COOLING PROCESS OF BLAST FURNANCE LINING

Water cooling systems are designed to operate in a closed loop rather than the conventional open systems. This allows the pipe work to be chemically cleaned, and by controlling water chemistry throughout the campaign this clean surface can be maintained, thus ensuring maximum heat transfer. The main function of the cooling system is to cool the furnace shell and prevent it from overheating and subsequent burn through. To accomplish this, the cooling system must be able to take up the excess heat generated by the furnace and loaded onto the shell. This heat will lift the shell and lining temperature too high if the cooling system is not effective in dispelling it. Over the years, the development of cooling systems has received a great deal of attention, especially in the last two decades. Two main competitors emerged for shell cooling, with still no clear advantage evident. The first of these is the so called cooling boxes, or sometimes better known as flat plate coolers. The second is the cast iron staves, which receive great attention especially in Japan. Where flat plate coolers, as the name describes, are flat plates that are arranged horizontally into the furnace shell, staves can be described as flat plates stacked parallel and flush to the inside of the shell and are cooled by a built in piping arrangement.

1.2 DIFFERENT COOLERS USED IN BLAST FURNACE

1.2.1 PLATE COOLERS

Nearly all the large European furnaces with cooling boxes use copper flat plate coolers. The usual plate sizes are 500 - 1000 mm long, 400 - 800 mm wide and approximately 75 mm high. Copper flat plate coolers are either welded or cast in electrolytic copper. With the latter, there are then no problems at the weld seams and there is a greater uniformity of the material properties over the complete cooling element. In the regions of the furnace which are subject to mechanical damage the front sides of the cooling elements are frequently reinforced with special materials.

To ensure a gas tight sealing the flat plate coolers are mostly welded to the shell. The copper flat plate coolers generally have multiple channels with one or two independent chambers. Minimum losses of water pressure are ensured in both the piping and the element itself .The Figure1.2 shows a typical copper flat plate cooler design.

Figure 1.2 Plate coolers (24)

1.2.2 CIGAR COOLER

For special blast furnace applications, Cigar Coolers can be either cast or fabricated in many different dimensions or lengths. The steel bands or flanges are welded to the cigar cooler for ease of installation in the field and to maintain a gas-tight fit. Cigar cooler given in Figure 1.3 .

Figure 1.3 Cigar Coolers (24)

1.2.3 STAVE COOLERS

In the region of the bosh, belly and lower stack a good cooling system design is of utmost importance to be able to cope with high heat loads and high temperature fluctuations. A recent development aimed specifically at this area is the use of copper staves shown in the Figure 1.4. Here staves are rolled rather than cast where the outer dimensions can be held to close tolerances. In addition, by boring the cooling passages directly into the rolled copper plates, the cooling water is directly in contact with the stave body, thus eliminating the thermal barrier of the coating on the cast-in pipes used in cast iron staves. These techniques, in conjunction with the high conductivity of copper, lead to much lower stave operating temperatures under all operating conditions.

Figure 1.4 Stave Cooler (24)

1.3 Different materials used in blast furnace

1.3.1 Properties of stave materials

These are the stave materials (Cast iron, Aluminium and Copper) which I have been used for heat transfer analysis given in Table 1.1.

Table1.1 Stave materials

S.N	**Stave Materials**	**Specific Heat (J/KgK)**	**Thermal Conductivity (W/mK)**	**Density (Kg/m^3)**
1	Cast iron	460	40	7500
2	Aluminium	871	202.4	2719
3	Copper	381	385	8978

1.3.2 Properties of refractory material

These are some refractory material which I have been used in this Analysis given in Table 1.2.

Table1.2 Refractory materials

S.N	**Refractory Materials**	**Specific heat (J/KgK)**	**Thermal Conductivity (W/mK)**	**Density (Kg/m^3)**
1	AL_2O_3	880	18	3690
2	SiO_2	700	1.4	2648
3	Mullite	760	12	2950

1.3.3 Refractory materials used in different area of blast furnace

Different types of refractory materials used in the different cross-sectional area of blast furnace are given in Table1.3

Table1.3 Refractory materials

Cross Sectional Area	Present
Hot blast stove	Al2o3(42-82%)
Tilting Spout	High alumina ,SiC,castables,
Main Trough	Clay,Pitch,Grog,castable,Tar and water ,
Tap hole	High Alumina , SiC tar .Fireclay tar.
Lower Hearth	42-62% Al_2O_3, Mullite, Conventional Carbon block
Tuyere	Mullite , Al_2O_3(62%)
Bosh	Mullite , Al_2O_3(65%)
Belly	Al_2O_3 (39-42%)
Stack	Al_2O_3 (39-42%)

1.3.4 Properties of fluid

I have been taken two types of fluid “water and nitrogen” used in this Analysis .The properties of fluid are given in Table 1.4.

Table1.4 Types of fluid

S.N	Types of fluids	Specific heat (J/KgK)	Thermal Conductivity (W/mK)	Density (Kg/m^3)
1	Water	4187	0.6	998.2
2	Nitrogen	1040	$25.83*10^{-3}$	1.251

1.4 The main benefits from using heat transfer analysis for blast furnace are –

- Prolonged hearth and furnace refractory life
- Extended furnace campaigns
- improved process information (from thermocouple locations)suitable for use with other models
- can be used as a diagnostic tool monitoring the wear rates in the refractory

1.5 Problem of water using in stave cooler

- Water sometimes causes incomplete combustion in blast furnace due to leakages or failure in a stave cooler which is a major problem for Furnace Operator.
- Scarcity of water gradually converting it to a rare commodity, whose availability for industrial use will be difficult after meeting basic requirements of human consumption, like agriculture, hospitals etc
- Create corrosion Problems in a Blast Furnace Water-Cooling System based on a soft-water supply

1.6 Benefit of nitrogen

- Nitrogen is abundantly available in the steel industry as bi-product. Hence its availability will not be a problem.
- Nitrogen is non-combustible, non reactive & inert in nature which can be used without a safety hazard as a cooling agent.
- It is available in atmosphere.

1.7 Main benefit of refractory lining

- Long lifetimes for maximum furnace campaign
- Cost effectiveness
- Rapid installation
- Heat and fire protection

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

Cheng-Peng Yeh et al. [1] analyzed heat transfer of various lining thickness using copper staves and sensor bars. The simulation results show for the significant shelter for the cooling stave body need refractory lining and slag shell. On the hot face of the staves, when the cooling staves open and slag (CaSio3) is freeze, then heat and temperature of hot wall surface of copper stave cooling body will be reduced comparison to the copper stave without using slag layers. However, the result indicated that residual refractory lining thickness can be measured by using copper sensor bar. These simulation results show that information of the BF operations and are significant for the prediction of the campaign life of blast furnace.

Gdula et al. [2] analyzed heat transfer of the blast furnace hearth(bottom portion) was based on different cooling system and lining material was considered. A method of the solution coupling is applied. The model has based on an original method is known as solution coupling method. The solution coupling methods consists mainly in splitting up the considered region into a number of sub regions. He had developed a computer program for this analysis. This computer program was applied to establish temperature and heat flux distributions which are of interest when designing both blast furnace cooling and lining systems Capable to deal practically with any existing blast furnace cooling system. A new cooling system can be easily included in this program without any significant change in the program.

Chang et al. [3] studied about the erosion occurs in the hearth portion of the blast furnace during tapping process. He had taken three kinds of height of his experiment; these are 10 centimetre, 30 centimetre and 50 centimetre from the bottom of the blast furnace. According to changing of height of the dead man will create more erosion at the different areas of the hearth. According to their simulative results, they found (1) we can observe the quicker flow in higher dead man and low carbon concentration means that minimization of the erosion rate needs a suitable height of the dead man. (2) For the protection of the hearth wall need higher carbon concentration at the inlet, but it must be improving the quality. (3)The distribution of porosity in the dead man is useful to decrease the erosions of refractory linings.

Y. Kaymak. [4] Carried out Simplified Approach to the Contact in Thermo-mechanical Analysis of Refractory Linings. The variations on hoop stresses in the refractory blocks of the three different simulation approaches are compared. The blue line was obtained from the standard axis symmetric models which do not consider the contact. Therefore, unrealistic tensile hoop stresses are obtained at the steel shell side of the blocks. The hoop stress variations obtained from the standard contact model (the red line through the canter of the block and green line through the contact boundary) do not have these unrealistic tensile stresses. It is also possible to conclude that the hoop stresses at the block canter and contact boundary are very similar. Finally, the introduced method (the purple line) provides a much faster model preparation and solution than the traditional contact models with an excellent accuracy.

Maria Swartling. [5] Studied about the Heat Flow in the Hearth of Blast Furnace. From the experimental and numerical calculations he determined the heat flows in a blast furnace hearth. Hearth portion of the blast furnace is exposed to maximum temperatures. Measurements of outer surface temperatures in the lower part of a blast furnace were carried out. In the experiment he studies, relations were established between refractory lining temperatures and outer surface temperatures of the blast furnace hearth. He predicted that the corner between the wall and the bottom is the most sensory part of the hearth. Furthermore, the predictions show that there is no studied part of the refractory lining had an inner temperature higher than the critical temperature 1050°C.

Wu Lijun et al. [6] these people were presented on intelligent monitoring method based on the mathematical model of heat transfer of blast furnace staves, they ware developed an intelligent simulation technique which model is made by combination of two models is the mathematical models of the heat flow and techniques of artificial intelligent. The intelligent simulation model of cooling stave is depends on correction factors parameter, these parameter are obtained from the sample test data. The experimental verification model was done. The results indicate that the data on to intelligence simulation models is nearly same with the experimental data.

Xu Xun et al. [7] studied about heat transfer analysis of cast steel stave and they used finite element method and design modular software. This investigation shows that numerical calculation and experimental results are same. The effect of Heat transfer analysis is depend on several parameters these are the cooling water temperature and flow velocity, the inter distance of cooling channels and diameter of the pipe, the refractory lining materials, water cooling scale, outside surface coating layer of water cooling pipe, gas clearance and hot surface of stave which have maximum temperature and thermal stress. It is indicated that the temperature of water decrease with increase the velocity of water would not be economical. Maximum temperature, thermal stress and heat transfer in the cast stave would control by adjusting proper operating condition of BF. The heat transfer of the cast stave, temperature of the cast stave and thermal stress of the cast steel stave cooler would be control by proper adjusting operating condition of the furnace, the operating condition are flow of gases, cooling water channel interdistance and pipe diameter, refractory lining materials, coating layers and gas clearance.

Zhou Weiguo et al. [8] studied about structural optimization of blast furnace cooling stave based on of heat flow analysis, they used design modular software to find out the thermal stress of cast stave steel and temperature of the cast stave steel and refractory lining. The heat flow of BF cast steel stave cooling is depends upon the parameters of blast furnace. The results show that the parameters value optimizes for the cast steel stave cooling is the cooling channels interdistance is 200 millimetre, inner radius of water channel is 25 millimetre, the cooling stave thickness is 180 millimetre, thickness of inlaid brick is 70 millimetre and speed of cooling water is 1.5 meter per second. Decreasing the temperature of water would not be economical. They choose the best refractory lining material is silicon nitrogen bond silicon carbide refractory and silicon carbide refractory.

Cheng Hui'er et al. [9] studied about the optimization of cooling channel in furnace heat transfer analysis on cast steel stave. They used design modular software and finite element analysis for this purpose and they also developed three dimension mathematical models and temperature of the stave and thermal stress of stave cooling was investigated. The results indicate that oblate pipe reason have high temperature of stave on hot surface was 10 to 20 degree centigrade more than an oval channel cooling system. On the other hand, oblate pipe have been some effect on the higher temperature of the stave cooling, therefore stave cooling hot surface is not stable. Therefore they not considered oblate tube is an ideal channel of furnace. The higher temperature of the red surface and thermal stress of the red surface is not high when elliptical tube used instead of cooling pipe. Because of decreasing the area of cross section of the cooling elliptical pipe, cooling stave thickness can be reduced and flow of cooling water is saved.

Peng Li et al. [10] studied about the equivalent convective heat transfer coefficients of blast furnace high temperature surface of the staves. They calculated the coefficient of heat transfer between flow of gas inside the blast furnace and surface of hot stave bodies. The combination of experimental and numerical calculation of the flow of gas and inlaid brick was constituted, when the temperature of gas is in the range of 500– C. These is the reason why the coefficient of heat transfer between flow of gas and inlaid brick is greater than that between gases and stave bodies, it had analyzed when the temperature of gas is maximum. The viewpoint just using the equivalent coefficient of heat transfer between flow of gas and staves while heat transferred model is changed. For higher accuracy of numerical calculation of heat transfer used two kinds of different equivalent convective coefficient.

Anil Kumar et al. [11] studied about computational model of stave cooling of blast furnace based on transfer of heat, they researched three dimension transfer of heat of cooling stave and thermal stresses of cast steel cooling staves in a blast furnace. They used design modular software and finite element method for the calculating temperature of stave of thermal stress field. In the CFD analysis, transfer of heat by radiation from solid material to inside face of stave is neglected, solid material which used are ore, flux and coke. They had taken two different refractory materials. These are the high alumina bricks and silicon carbide bricks. This refractory lining material are used at different loads at different positions, i.e., the temperature of gas varies from 770 K to 1570 K. Initial temperature of water is taken as 300 K. The result shows that the higher temperature of hot surface and the hot surface thermal stress are highest at silicon carbide bricks and lowest at high alumina bricks. And further the result shows that the silicon carbide bricks are better because of it can withstand higher temperature at various circumstances which affect the life of cooling stave off the blast furnace. Hence the suitable refractory lining for the staves are the silicon carbide bricks.

Akash Shrivastava. [12] he studied about Reliable furnace cooling technology is a region of increasing concern to the metallurgical industry as it can significantly increase process intensities, productivity and campaign life of blast furnace. He reviewed of blast furnace stave cooling refractory lining materials used in the metallurgical industry based on heat extract analysis. In this field of researched he had taken two types of refractory materials are silicon carbide brick and high alumina bricks and blast furnace cooling stave and two types of skull is considered. in which the first have negligible thickness and the second one is having certain thickness in millimetre, so, with these two skulls, the heat transfer analysis will be done at different temperatures from 763k to 1563k in order to compare which refractory lining will give better results than the other.

Karel Verscheure et al. [13] had done a reviewed on different cooling designs used in the ferrous material, non-ferrous material. Further, they also reviewed on different aspects of materials selection, manufacturing, installation, and water quality when using water cooled refractory etc. Although there are many advantages in using furnace cooling systems, they had also imposed a variety problem related to safety, heat to flow and sustainability of the operations.

Luis Felipe Verdeja et al. [14] studied about temperature distribution by using finite element method. They simulated by using FE method ,the nitride is the ceramic solution and ceramic oxide contact with pig iron and the carbon and further refrigeration system is contact with micro porous graphite block. After that comparing the distributions of temperature calculated by using FE method in the crucibles of the furnace and the layout of material proposed to the ceramic solutions and thermic solutions, it is obvious that when the materials of liquid pig iron is contact with ceramic materials and the carbon based material with the refrigeration system, The 1,201°C isotherms is close to the melt refractory interface. The ceramic solutions are the mostly adequate for the materials distribution to minimize the wear.

Hugu Joubert. [15] He analyzed about blast furnace lining and cooling system using computational fluid dynamic. He used semi graphite refractory material for use in the boss, belly and lower stack region of the blast furnace. He got some advantage using copper stave over flat plate cooler are (1) hot surface and refractory lining temperature are lower and then skull formation will be better. (2) heat flux and temperature fluctuation can better dealt with.(3)steam formation in the cooling water channel is less likely to occur and better physical support is given to the refractory brick work. so that copper stave cooler is used for better cooling performance.

Gabriel Plascencia. [16] He studied Exchange of heat in Furnace Side Walls with the Water Cooled Cooling Devices. He was tested three different types of coolers. He ware purposed to compared with the thermal response and the oxidation behaviours of the bare copper material and protect copper material. He had immersed the cooling elements directly into the molten and the molten slag with no refractory lining protective cover. This reason was for performing the tests of this fashion to evaluated the capacity of protected copper to transfer heat from the molten phases and then compare such capacity with that of the un-protected copper material., In this study, the ultimate goal is to evaluated the thermal behaviour and oxidation behaviour of the material that might be used to construction of cooling systems.

Yoshiyuki Matsui et al. [17] studied about Centralized Gas Flow by Canter Coke Charging of a blast furnace operational technology. He suggested that the steel industries will be moving toward future for higher value added product. As per the investigation result, the coke reaction load is increased with respect to the decrease of pulverized coke ratio when the Pulverized Coke ratio is constant increasing coke fines in the dead man. In order to handle at a lower reductant ratio, further improvement in gas and liquid permeability of the dead man coke is required for the increased coke fines.

Xuefeng YANG et al. [18] studied about mechanism of zinc damaging the tuyere of refractory lining of blast furnace. The investigation and test results manifest that the enrichment and the main leading factors of the upward warp of the tuyere is the expansion of zinc in the tuyere bricks. Eroding behaviours of Zn is the inside structures of the tuyere brick change from dense level to loose level with reducing and expanding of zinc metal, Further, they got the sequence of damage element Entering the tuyere refractory lining are Potassium**,** Sodium, zinc and lead respectively. Finally, the process of zinc crystallizations and growth in the lining has been clearly investigated and recorded during their investigation.

J. Salgado et al. [19] studied about Control of refractory lining wear by using radioisotopes. They found wear rate depends upon the working conditions of the blast furnace and is not uniform. They measured the wear rate varies between 0.49 and 0.74 mm/charge.

Ulf Engman. [20] He studied about Erosion testing of refractories. He was used four different ceramic materials for the investigation procedure; such as refractory bricks, two cast able refractories and ceramic materials. A metallic materials had used for equipments calibration. The investigation result show that the pre erosion removes most of the initially at the transient state. Such as, velocity of particles are 40 meter per second and lining temperature is 800 degree centigrade, the result indicate that three hours of exposure the erosion at the perpendicular impingement in steady state . For almost all the ceramic sample there are tendency towards decreasing erosion wastage which is more pronounce at oblique angles. There is needed more times to some extra measurement of oblique angle. At 30 degree oblique angle more test time are needed to obtained steady states. The deviation from results seemed that the angle depends and which is higher at than compared to impingement, possibly at more oblique angle is less erosion waste. However, the conclusion is that the equipment and test procedures are useful for obtained steady state wastage results of non homogeneous ceramics materials.

D A bell. [21] he studied about Design of Refractory linings Using Computer based Thermo mechanical Analysis, On application of heat the refractory's lining expand and irnposing a more stress upon the shell side. He had calculated these stresses using a non-linear finite-difference analysis; and optimization of design is possible on computer program. He developed computer techniques for the thermal analysis and stress analysis has improved refractory linings design procedures. On the theoretical basis it has possible to calculate temperatures and stresses, strains on blast furnaces.

CAO Feng et al. [22] had research about Effect of Rheological Behaviour of Particle-Water Suspensions on Properties of Gunned Refractory for Blast Furnace. He investigated about relationship between the fluidity of refractory lining particle water suspension and that of gunned refractory lining, and the relationship between the fluidity and adhesion ability of gunned refractory lining. The investigation was carried out with a special rheometer and gunning machine .The results of rheological experiments indicate that different gelatinous structures are formed while silica dust is hydrated, in which quite a some free water is kept. At the time of gunning, the free water is released under the impact humidifying the big particles of gunned refractory lining. Therefore the adhesive strength between the refractory lining and gunned layer is increased.

YANG Da-zheng et al. [23] studied about Application of Ceramic Coat Synthesized by In-Situ Combustion Synthesis to blast furnace Tuyere. They investigated In-situ combustion synthesized ceramic coatings is suitable for produced the protective layers on the inner surface, outer surface, bottom and top surfaces of the tuyere. For that, it was a novel technique for tuyere protection for the blast furnace. The tuyere crack is due to the impurity of the copper material and the hot blast corrosion'. In-situ combustion synthesized ceramic coatings is composed of alumina and chromium nitride, it's all phases had high melting points; therefore its fire resistance temperature is more than 1800 degree centigrade, which is able to withstanding the erosion of hot metal and slag. In-situ combustion synthesized ceramic coatings inert phase has high melting points; therefore, it cannot react with melted iron and slag. The Heat transfer and difference in the in-situ water temperature measurement result show that the energy-saving efficiency of in-situ combustion synthesized ceramic coating tuyere is better.

2.1 Summery

After going through relevant journals it is found that different material are used in refractory material and analyzed the stave cooler using cooling medium water, but even not studied about thickness of refractory lining also not used nitrogen in the place of water for cooling the refractory lining.

CHAPTER 3

EXPERIMENTAL AND NUMERICAL ANALYSIS

3. EXPERIMENTAL AND NUMERICAL ANALYSIS

3.1 EXPERIMENTAL ANALYSIS

This work is about the three dimensional modelling and numerical analysis of the actual stave coolers with refractory lining used in blast furnace of Rourkela Steel Plant. we have identified a stave cooler for experimental base which is subject to maximum heat load in the furnace. A analytical model has been developed the with the help of ANSYS-13 software taking actual dimension from RSP data base. To develop the model we have design the dimensionally identical cooling coil with the help of work bench. The cooling coil developed is super imposed in a rectangular box dimensionally identical to the subjected experimental stave cooler. The model developed is exactly dimensionally identical to the actual stave cooler used in RSP .The model developed with the help of work bench is export to fluent to study the theoretical heat transfer behaviour of stave cooler vis a vis the actual heat load in the furnace.

We take the practical data from the experimental set up based on the same identified stave cooler of the blast furnace.

The experimental base is consisting of two numbers of temperature measuring devices fitted to the inlet and outlet of subjected stave cooler. Volume flow meter is installed in the inlet line to measure the volume flow inside to the stave cooler. A pressure gauge is installed in the fluid flow line to indicate the fluid pressure in the subject stave cooler.

From the experimental set up we measure the actual heat load in subject stave cooler table given below; we noted the inlet and outlet temperature and difference of temperature there off in the stave cooler (dT) in a particular volume of fluid flow.

When the same heat load calculated from experimental set up is put in analytical model. The temperature difference (dT) found to be as in the actual set up. The above experimental is continued for different types of fluid in our setup. We have measured the experimental setup value using water as cooling medium and then we replace it with nitrogen. The value obtained practically found to be exactly identical as in the software model. The experimental setup as shown in the Figure 3.1

Figure 3.1 Experimental setup

3.1.1 Experimental Data

These are some experimental data taken from Rourkela steel plant using water as a cooling agent given below in Table 3.1.

Table 3.1 Experimental Data

Stave cooler	Inlet temp(T_1) in ^oC	Outlet temp(T_2) in ^oC	Difference ($T=T_2-T_1$)	Water collected (litres)	Time in second	Volume (m3/hr)	Heat extract (kcal/hr)
1	27.4	32.8	5.4	30	54	2.00	10800.00
2	27.4	30.8	3.4	30	64	1.69	5737.50
3	24.4	30.8	6.4	30	60	1.80	11520.00
4	24.4	35.6	11.2	30	48	2.25	25200.00
5	24.4	33.2	8.8	30	46	2.35	20660.87
6	24.4	31.4	7	30	43	2.51	17581.40
7	24.4	32.8	8.4	30	57	1.89	15915.79
8	24.4	35.4	11	30	44	2.45	27000.00
9	24.4	34	9.6	30	47	2.30	22059.57
10	24.4	32.6	8.2	30	43	2.51	20595.35
11	24.4	31.6	7.2	30	52	2.08	14953.85
12	24.4	30.6	6.2	30	54	2.00	12400.00
13	24.4	32.8	8.4	30	48	2.25	18900.00
14	24.4	37.6	13.2	30	53	2.04	26898.11
15	24.4	30.2	5.8	30	48	2.25	13050.00
16	22.4	30.4	8	30	51	2.12	16941.18
17	22.4	30.4	8	30	48	2.25	18000.00
18	22.4	28.4	6	30	53	2.04	12226.42
19	22.4	28.2	5.8	30	58	1.86	10800.00
20	22.4	27.8	5.4	30	54	2.00	10800.00
21	22.4	29	6.6	30	55	1.96	12960.00
22	22.4	30.2	7.8	30	58	1.86	14524.14
23	22.4	30.2	7.8	30	59	1.83	14277.97
24	22.4	27.2	4.8	30	51	2.12	10164.71
25	22.4	32.8	10.4	30	53	2.04	21192.45
26	22.4	33.4	11	30	47	2.30	25276.60
27	22.4	35.4	13	30	54	2.00	26000.00
28	27.4	37.4	10	30	53	2.04	20377.36
29	27.4	31.4	4	30	48	2.25	9000.00
30	27.4	32.2	4.8	30	52	2.08	9969.23
31	27.4	33.2	5.8	30	47	2.30	13327.66
32	27.4	34.2	6.8	30	69	1.57	10643.48
33	27.4	37.2	9.8	30	46	2.35	23008.70
34	27.4	31.2	3.8	30	58	1.86	7075.85

35	27.4	30.6	3.2	30	53	2.04	6520.75
36	27.4	30.6	3.2	30	52	2.08	6648.15
37	27.4	32.4	6	30	55	1.96	9818.18
38	27.4	29.6	2.2	30	58	1.86	4096.55

Stave cooler	Inlet temp(T_1) in ^oC	Outlet temp(T_2) in ^oC	Difference ($T=T_2-T_1$)	Water collected (litres)	Time in second	Volume (m3/hr)	Heat extract (kcal/hr)
Loop-1							
2-4	24.8	31.4	6.6	30	42	2.57	16971.43
5-7	24.8	32.8	8	30	6 8	1.59	12705.88
8-10	24.8	30.8	6	30	40	2.70	16200.00
11-13	25.2	33.4	8.2	30	33	3.27	26836.36
14-16	25.2	34	8.8	30	36	3.00	26400.00
17-19	25.2	35.6	10.4	30	29	3.72	38731.03
20-22	25.2	34.8	9.6	30	32	3.38	32400.00
23-25	25.2	33	7.8	30	58	1.86	14524.14
26-28	26	36.4	10.4	30	34	3.18	33035.29
29-31	26	34.2	8.2	30	30	3.60	29520.00
32-1	26	33.2	7.2	30	40	2.70	19440.00
Loop-2							
2-4	24.8	29.8	5	30	31	3.48	17419.35
5-7	24.8	33.2	8.4	30	41	2.63	22126.83
8-10	24.8	30.8	6	30	42	2.57	15428.57
11-13	25.2	40.4	15.2	30	60	1.80	27360.00
14-16	25.2	37.2	12	30	40	2.70	32400.00
17-19	25.2	32.8	7.6	30	30	3.60	27360.00
20-22	25.2	33.6	8.4	30	31	3.48	29264.62
23-25	25.2	32.6	7.4	30	46	2.35	17373.91
26-28	26	33.4	7.4	30	27	4.00	29600.00
29-31	26	40.8	14.8	30	67	1.61	23856.72
32-1	26	33.6	7.6	30	32	3.38	25650.00
Loop-3							
2-4	24.8	31.2	6.4	30	157	0.69	4402.55
5-7	24.8	27.6	2.8	30	97	1.11	3117.53
8-10	24.8	28.8	4	30	100	1.08	4320.00
11-13	25.2	29.2	4	30	92	1.17	4695.65
14-16	25.2	30.8	5.6	30	161	0.67	3756.52

17-19	25.2	28.6	3.4	30	72	1.50	5100.00
20-22	25.2	30.2	5	30	107	1.01	5046.73
23-25	25.2	30.2	5	30	108	1.00	5000.00
26-28	26	29.8	3.8	30	80	1.35	5130.00
29-31	26	31.4	5.4	30	101	1.07	5774.26
32-1	26	29.4	3.4	30	44	2.45	8345.45
Stave cooler	Inlet temp(T_1) in ^oC	Outlet temp(T_2) in ^oC	Difference ($T=T_2-T_1$)	Water collected (litres)	Time in second	Volume (m3/hr)	Heat extract (kcal/hr)
Loop-4							
2-4	26.4	41	14.6	30	30	3.60	52560.00
5-7	26.4	33.8	7.4	30	27	4.00	29600.00
8-10	26.4	37.6	11.2	30	36	3.00	33600.00
11-13	24.8	45.6	20.8	30	30	3.60	74880.00
14	24.8	27.2	2.4	30	40	2.70	6480.00
15	24.8	29	4.2	30	51	2.12	8894.12
16	24.8	27.8	3	30	67	1.61	4835.82
17-19	24.2	30.6	6.4	30	36	3.00	19200.00
20-22	24.2	41.2	17	30	30	3.60	61200.00
23-25	24.2	33.6	9.4	30	28	3.86	38257.14
26-28	25.2	35.6	10.4	30	21	5.14	53485.71
29-31	25.2	36	10.8	30	33	3.27	35345.45
32-1	25.2	36.6	11.4	30	40	2.70	30780.00
Loop-5							
2-4	26.4	34.4	8	30	39	2.77	22153.85
5-7	26.4	38.6	12.2	30	29	3.72	45434.48
8-10	26.4	37.6	11.2	30	29	3.72	41710.34
11-13	24.8	42.8	18	30	41	2.63	47414.63
14-16	24.8	40.2	15.4	30	59	1.83	28189.83
17-19	24.8	41.4	16.6	30	35	3.09	51222.86
20-22	24.2	37.2	13	30	45	2.40	31200.00
23-25	24.2	31	6.8	30	41	2.63	17912.20
26-28	25.2	38.2	13	30	45	2.40	31200.00
29-31	25.2	34.2	9	30	32	3.38	30375.00
32-1	25.2	37.2	12	30	32	3.38	40500.00
Loop-6							
2-4	26.4	31.2	4.8	30	79	1.37	6562.03
5-7	26.4	29.8	3.4	30	54	2.00	6800.00
8-10	26.4	30.8	4.4	30	79	1.37	6015.19

11-13	24.8	28.2	3.4	30	44	2.45	8345.45
14-16	24.8	28.6	3.8	30	52	2.08	7892.31
17-19	24.8	29.6	4.8	30	58	1.86	8937.93
20-22	24.2	28.2	4	30	62	1.74	6967.74
23-25	24.2	28.6	4.4	30	69	1.57	6886.96
26-28	25.2	29.2	4	30	60	1.80	7200.00
29-31	25.2	31.4	6.2	30	58	1.86	11544.83
32	25.2	28.2	3	30	70	1.54	4628.57
33-1	25.2	30.2	5	30	63	1.71	8571.43

3.1.2 Experimental data using Nitrogen as cooling agent.

These are some experimental data taken from RSP using nitrogen as a cooling agent instead of water given below in Table 3.2

Table 3.2 Experimental data of nitrogen as cooling agent

S.N	No. of turns	Valve opening percentage	Inlet temp	Outlet temp
1	2	66.67%	29	29.3
2	3	50%	29	32
3	4	33.33%	29	39
4	5	16.67%	29	39
5	6	1%	29	41

3.2 NUMERICAL ANALYSIS

3.2.1Computational analysis

In Present study model of blast furnace refractory lining with cooling is done by the help of software ANSYS-13. In this software workbench is specially used for geometry and meshing of the model. There are some steps explain below:

Geometric Modelling: A three dimensional refractory lining with stave cooling having original dimension of 1640 mm length, 898mm height and 850mm width is drawn by the help of design modular. First of all I have drawn coil of the stave having dimension of 33mm diameter and 8421mm total length and the bending radius of the coil is 80mm as shown in the Figure 3.1and Figure 3.2 respectively .After completion of the coil I have drawn the stave body with coil of 1640mm length,898mm height and 200mm width as shown in the Figure 3.3 and Figure 3.4, Further it was extruded by 650mm in z-direction for addition of lining material as shown in the Figure 3.5 and Figure 3.6 respectively.

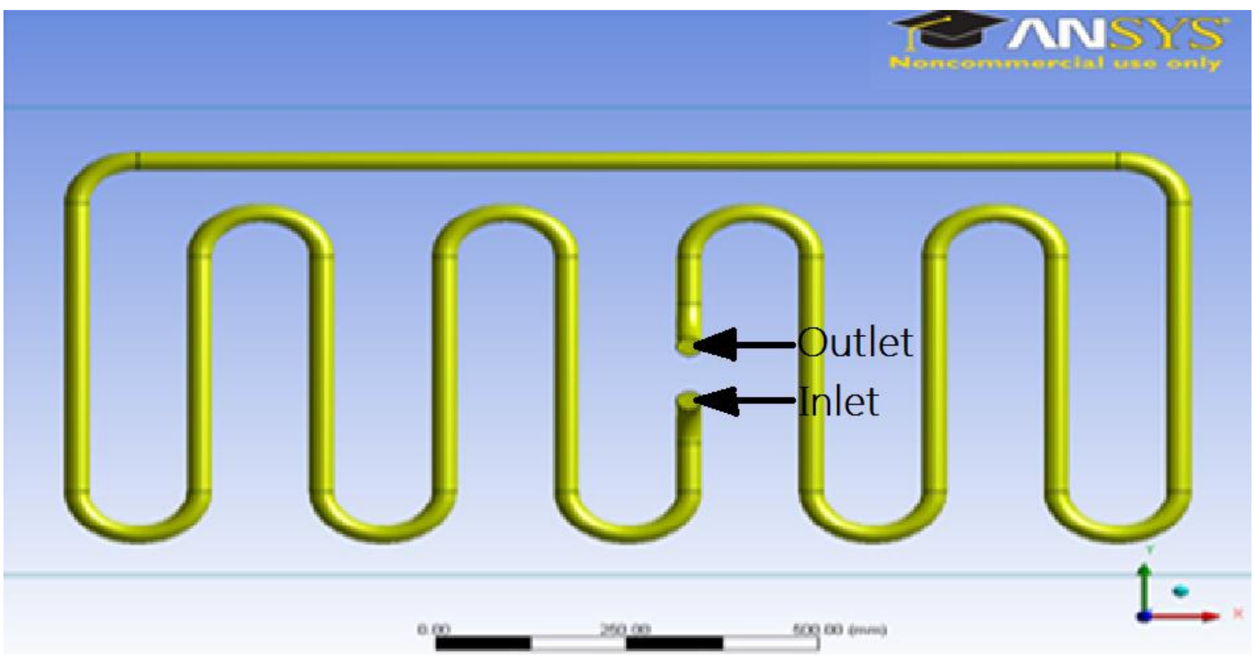


Figure 3.2 Stave coil in x-y coordinates

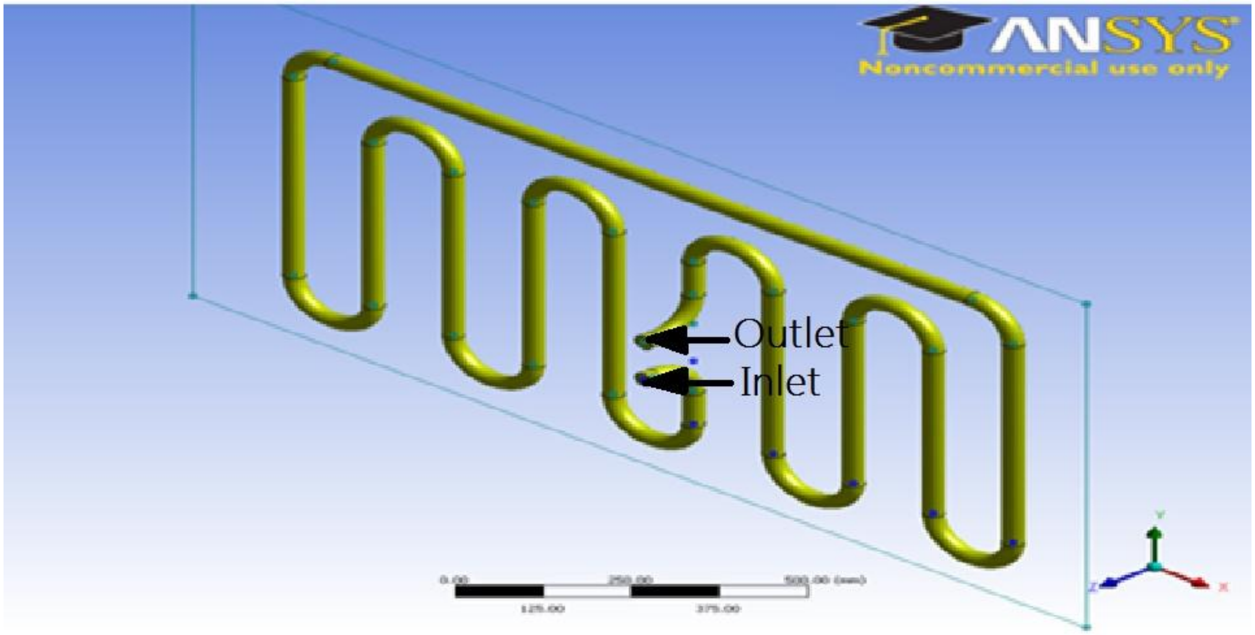


Figure 3.3 Isometric view of stave coil

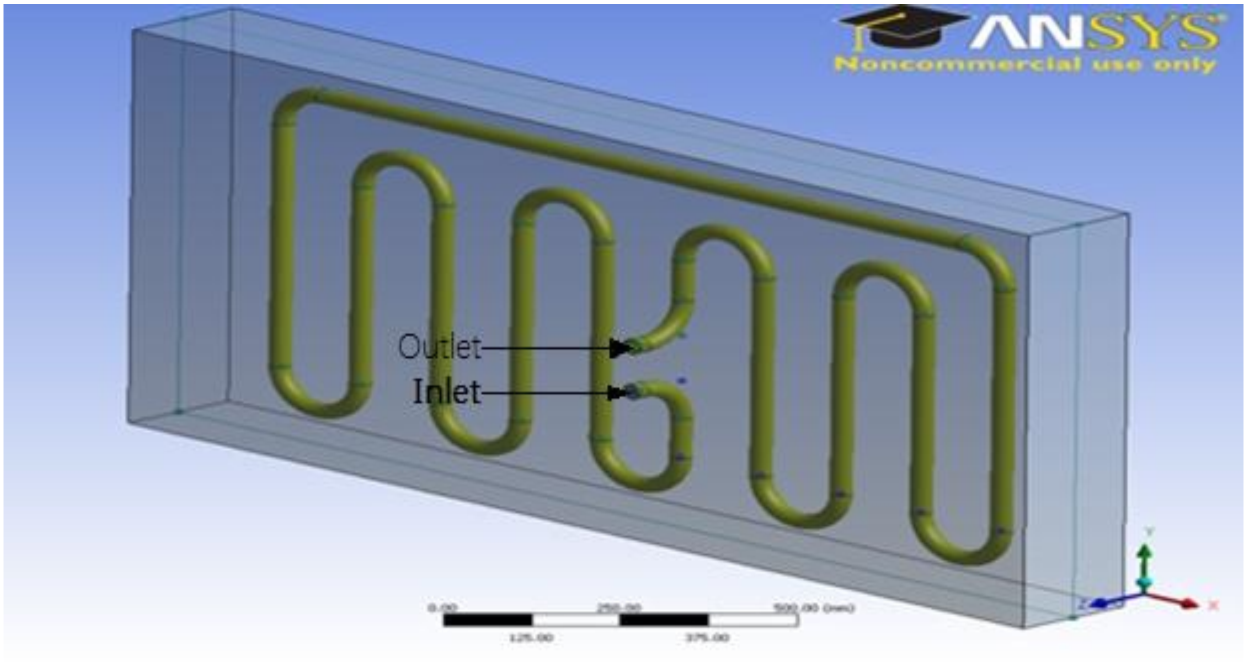


Figure 3.4 Isometric view of stave cooler

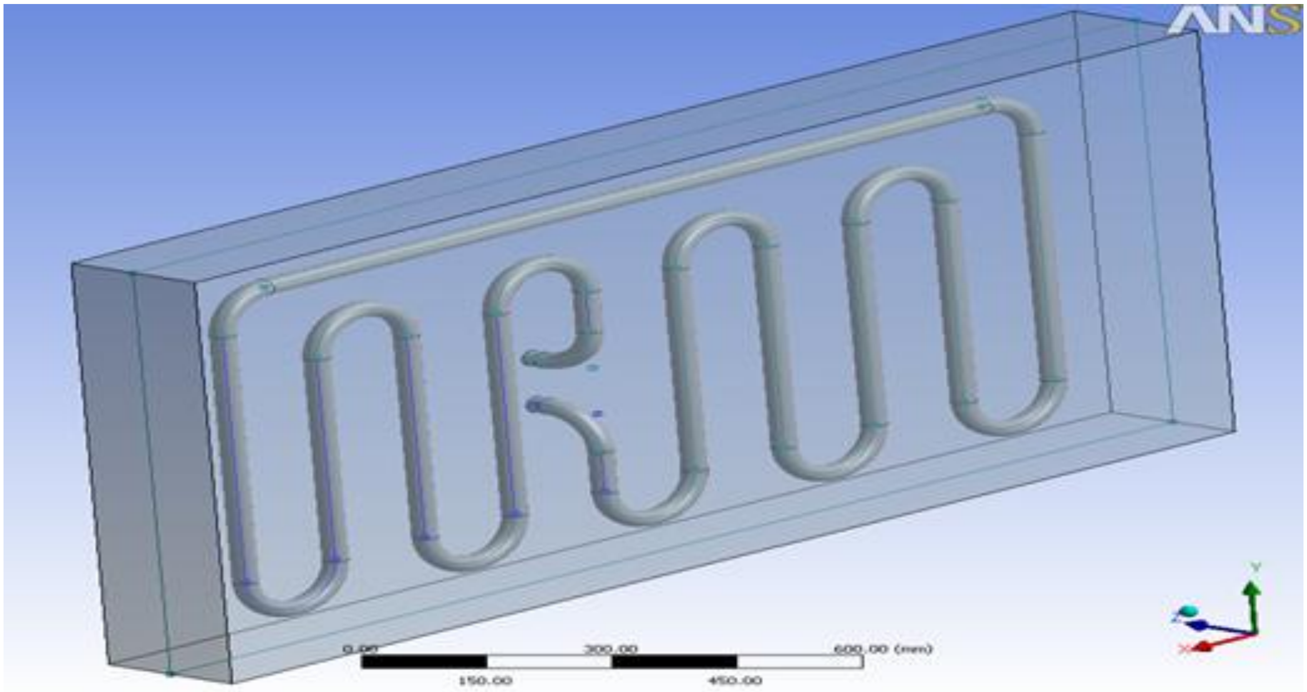


Figure 3.5 Back side of stave cooler

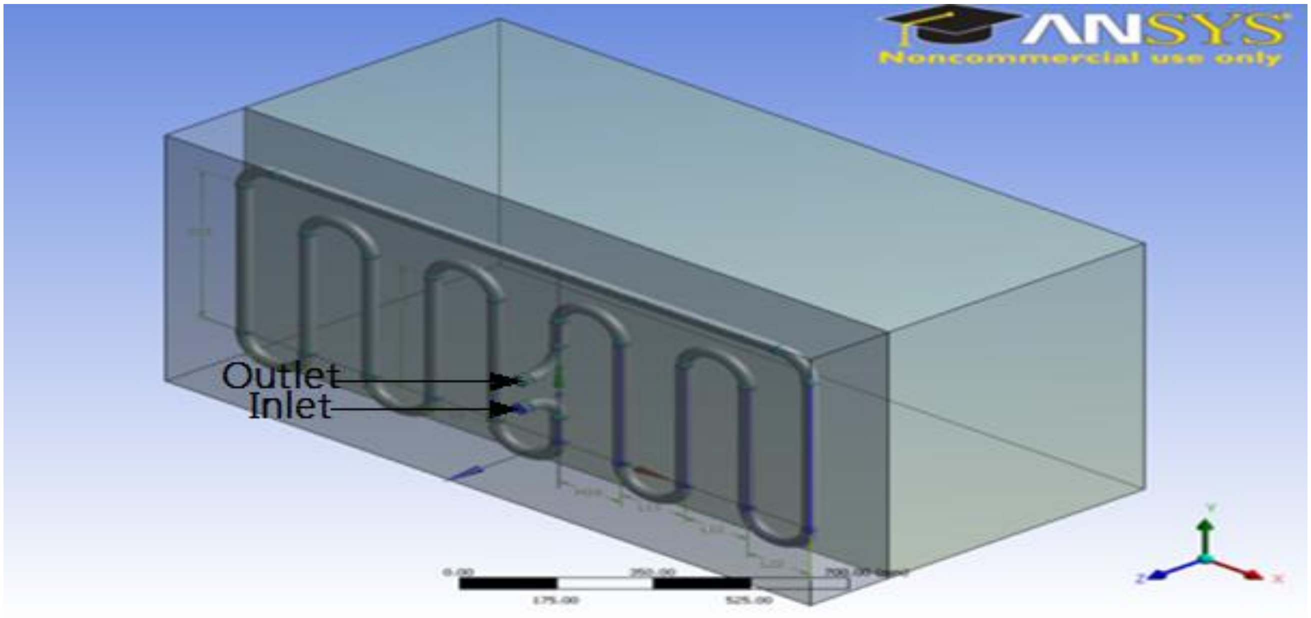


Figure 3.6 Isometric view of stave cooler with refractory lining

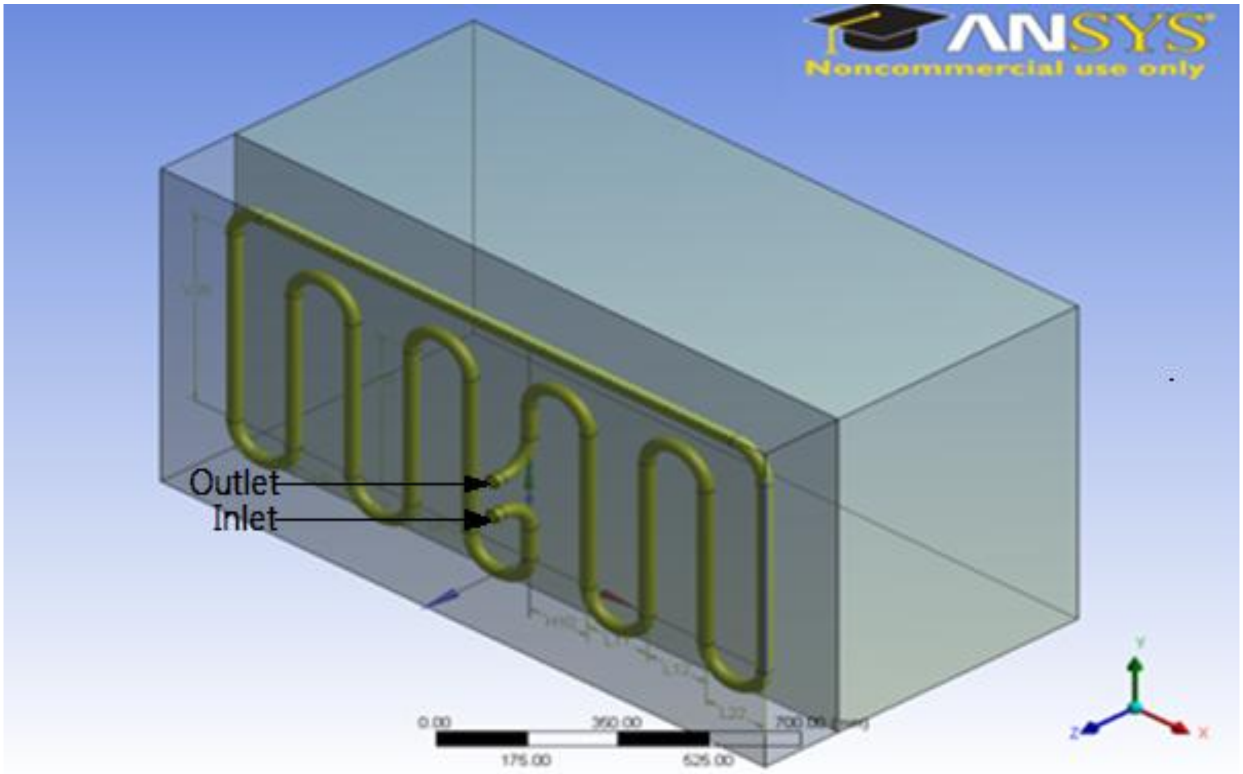


Figure 3.7 Isometric view of stave cooler with refractory lining

Mesh generation- After drawing the geometry of refractory lining with stave cooler in ansys workbench it is exported to mesh and then select contact region (contact body is fluid and target body is stave).then right click on mesh - insert – contact sizing then go to details of contact sizing and select contact region (fluid to stave) then select relevance is 100 then select generate mesh. It will be take few minute for generation of mesh. The meshing of different cases is shown in Figure 3.7, Figure 3.8 and Figure 3.9 respectively.

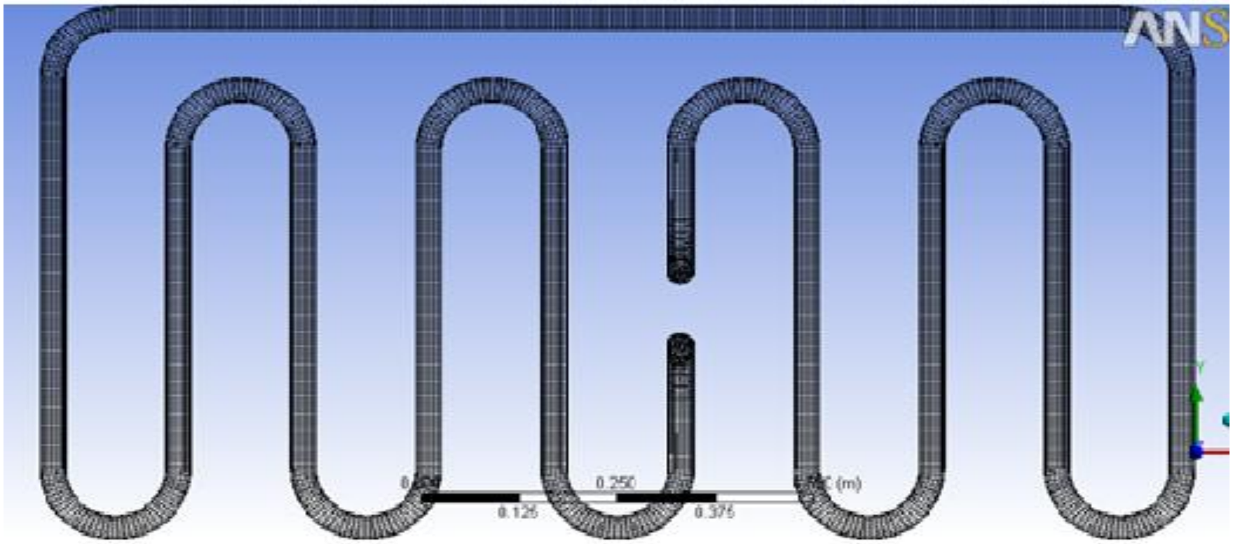


Figure 3.8 meshing of stave coil

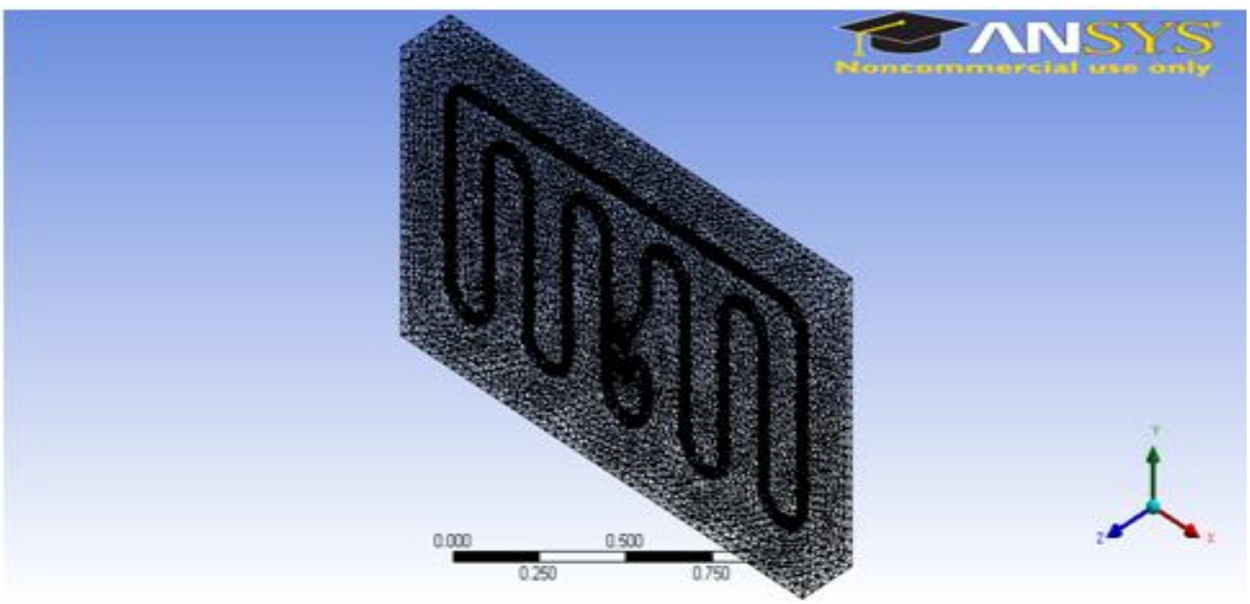


Figure 3.9 meshing of stave cooler

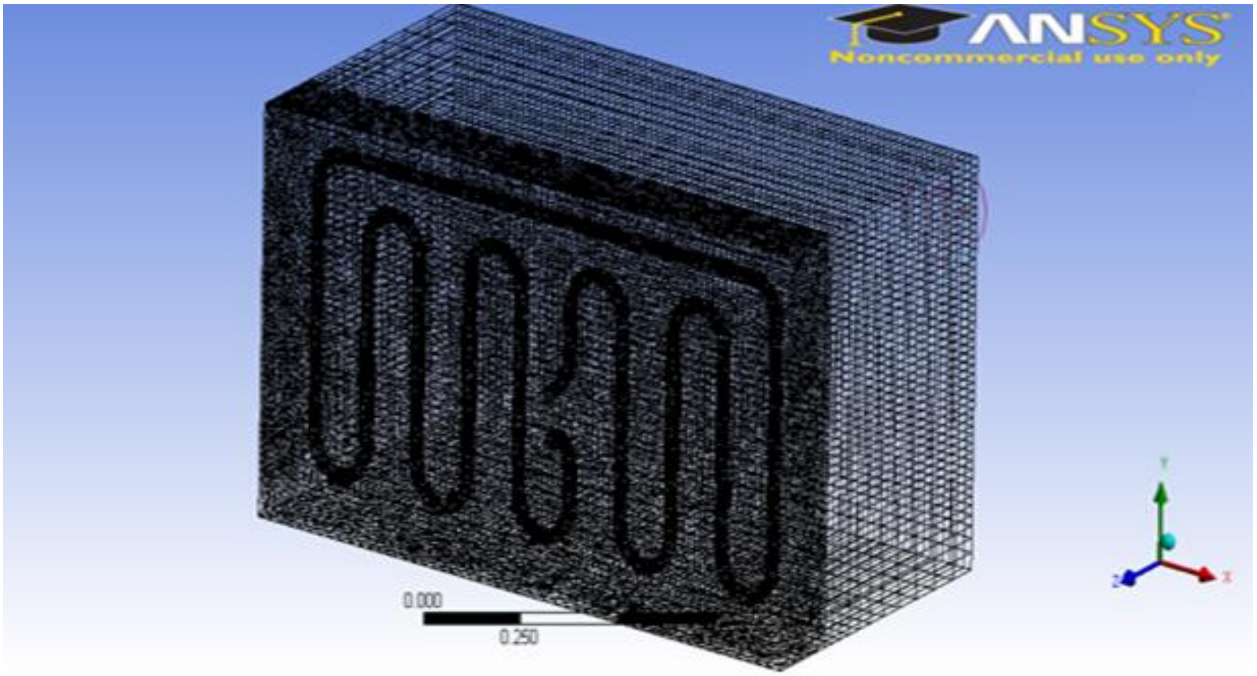


Figure 3.10 meshing of stave cooler with refractory lining

FLUENT SETUP:-

Meshing file has been generated in workbench, which has imported into FLUENT for the analysis of stave with refractory lining.

Problem setup:

- Select general- click on scale and convert meter to millimetre.
- Models-double click on energy-select energy equation-ok and double click on viscous-select k-epsilon (2 eqn) then ok.
- Materials-double click on fluid-click on fluent database-select water liquid-copy-close-change/create-close then double click on solid-click on fluent database-change material type fluid to solid-select solid material like (copper, aluminium etc)-copy-close-change/create-close.

- Cell zone conditions-double click on fluid-change material name air to water liquid-ok then double click on part 2 refractory-change material name-ok then again double click on part 2 stave-change material name –ok.
- Mesh interface-click on create/edit-select interface solid/ liquid give any name in mesh interface and select coupled wall-create-close.
- Boundary conditions are-heat flux, mass flow rate, initial temperature of inlet/outlet is 300K,
- Dynamic mesh-select dynamic mesh-smoothing.
- Reference value-select heat face in compute form and select part 2 refractory in reference zone.
- Solution method-select second order upwind in momentum, turbulent kinetic energy, turbulent dissipation rate and energy.
- Monitors-double click on residual-write 1e-06 in all parameters except energy-ok.
- Solution initialization-select mass flow rate in compute form then initialize.
- Run calculation –give number of iteration then calculate.

3.2.2 BASIC EQUATION OF FLUID FLOW

1. Continuity Equation:

$$\frac{\partial\ \rho u}{\partial x}+\frac{\partial\ \rho v}{\partial y}+\frac{\partial\ \rho w}{\partial z}=0 \tag{1}$$

2. Navier-Stokes Equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho x-\frac{\partial p}{\partial x}+\frac{1}{3}\mu\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 u \tag{2}$$

3. Energy Equation: (3)

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\left(u\frac{\partial p}{\partial x}+v\frac{\partial p}{\partial y}+w\frac{\partial p}{\partial z}\right)+k\nabla^2 T+\mu\phi$$

Where, $\phi=2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]+\left[\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2+\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2\right]$

$$-\frac{2}{3}\left[\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right]^2$$

Formulae used for calculation of heat extracted

Heat extracted Q (Kcal/hr)

$$Q=m\times C_p\times dT \tag{4}$$

Where, m = Weight of the water in kg

Cp= specific heat of water in kcal/kg^{0}C

T_2 = outlet temperature of water in ^{0}C

T_1 = Inlet temperature of the water before it enters the furnace in ^{0}C

Fourier's law of heat conduction:

This law is used for conduction heat transfer to find out heat or heat flux of the substance. The negative sign indicate of the decreasing temperature along with the direction of increasing thickness or the direction of heat flow. The temperature gradient is always negative along positive x-direction and therefore the value of Q become positive.

$$Q = -K \times A \times \frac{dT}{dx} \quad (5)$$

Where, Q=heat flow through lining per unit time (W)

A=surface area of heat flux, m^2

K=thermal conductivity of block, W/m °C

dT =temperature difference of the faces of block in °C

dX=thickness of block in the direction of heat flow,m

Above formulae are used for solved the problem of fluid flow. In fluent, Finite volume method is used to calculate the temperature of different direction in a object. In this problem energy equation is used. The above continuity equation is based on principle of conservation of mass, navier stoke equation and energy equation is based on principle of conservation of energy.

CHAPTER 4

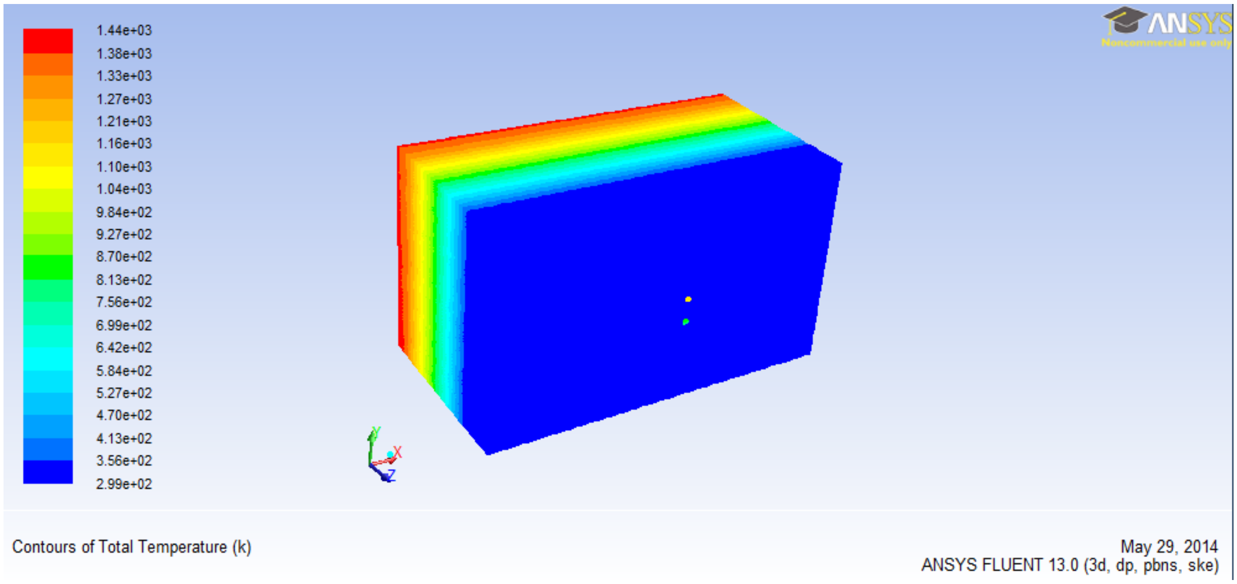
RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

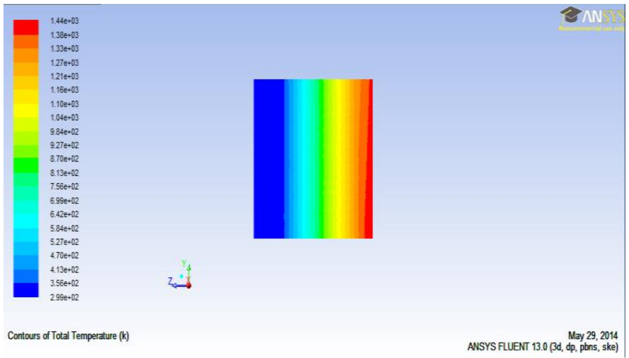
The numerical analysis has been done for the refractory lining with stave cooler by choosing both water and nitrogen as a cooling agent and have compared the temperature difference generated at the inlet and outlet of stave cooler.

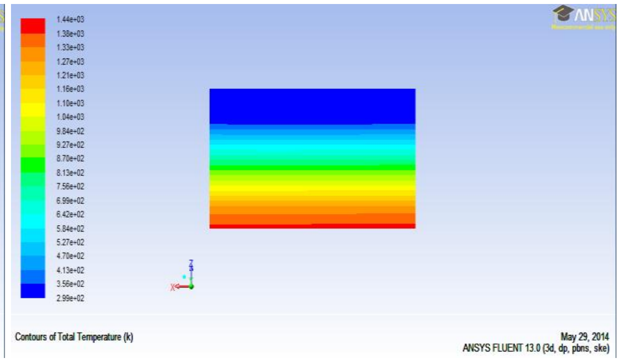
Numerical analysis of staves with refractory lining contour has been shown in Figure 4.1(a). It shows the variation of temperature across the surface of the stave material with refractory lining for thickness of 650mm. The heat wall (innermost surface of the refractory lining) shows the highest temperature of 1440 K. This is because heat flux is directly applied to this surface. With increase in distance in a direction away from the heat wall, the temperature gradually decreases. At the interface of the refractory lining and the stave material temperature was found to be 397 K. Inlet temperature of the cooling fluid was 300 K and at outlet its temperature was found to be 307.8K, which shows 7.8 K rise in temperature.

Fig 4.1. (b) to (e) shows the various cross-sectional view of refractory lining with stave cooler.

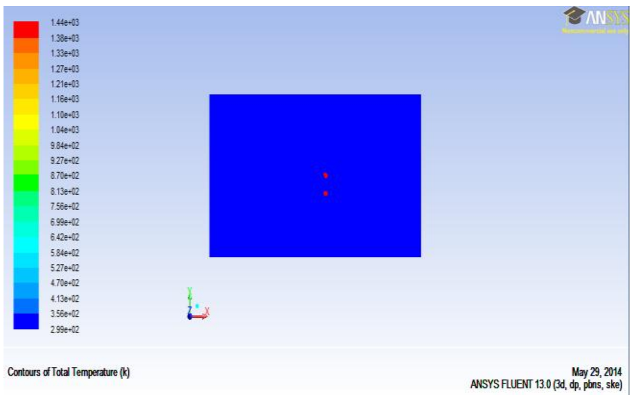


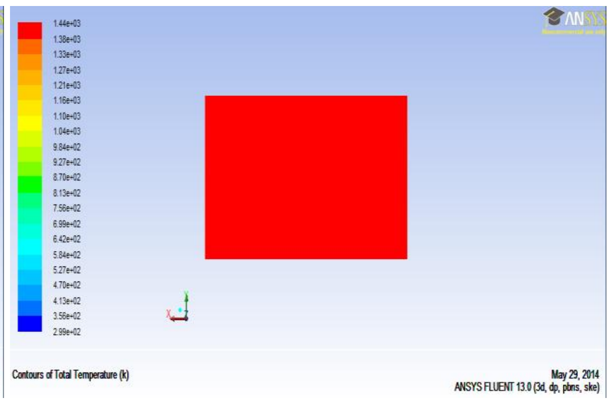
(a)





(b) **(c)**



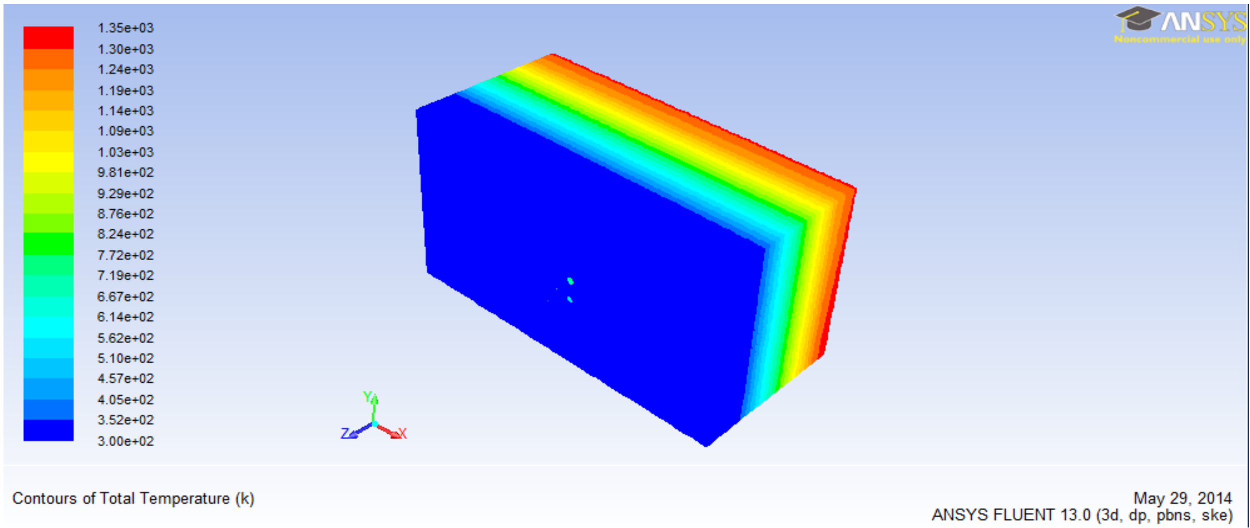


(d) **(e)**

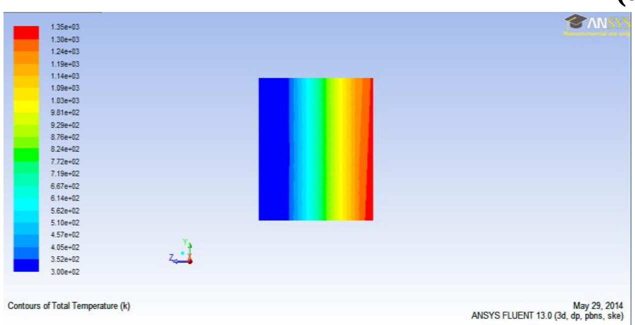
Figure 4.1 3D model of refractory lining (650mm) with stave cooler (a) Isometric view (b) Side view (c) Top view (d) Front view (e) Rear view.

Fig.4.2 (a) shows the variation of temperature across the surface of the stave material with refractory lining for thickness of 600mm. Heat wall shows the maximum temperature of 1350K, where as interface of the refractory lining and stave showed a temperature 408K. Same inlet temperature of 300K was given for cooling fluid, where the outlet temperature was found to be 310 K, showing a rise of 10K.

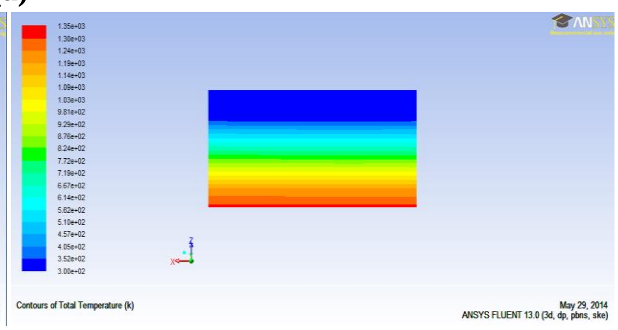
Fig.4.2. (b) to (e) shows the various cross-sectional view of refractory lining with stave cooler.



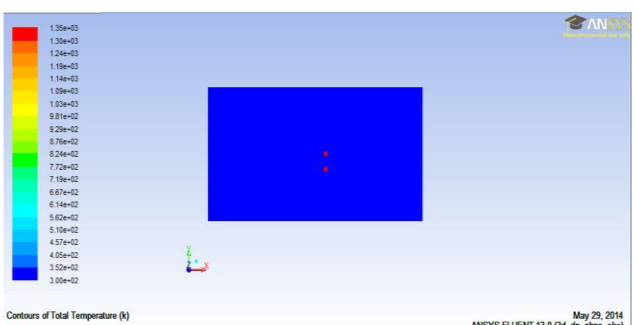
(a)



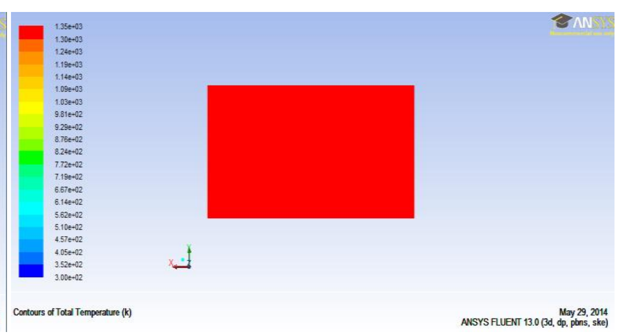
(b)



(c)



(d)



(e)

Figure 4.2 3D model of refractory lining (600mm) with stave cooler (a) Isometric view (b) Side view (c) Top view (d) Front view (e) Rear view.

In Fig.4.3 (a) we are showing the variation of temperature for refractory lining of thickness 550 mm. Heat wall temperature was found to be 1260K, and interface temperature was found to be

411K. Here temperature difference between inlet and outlet of the cooling coil was found to be 13K. Fig.4.3. (b) to (e) shows the various cross-sectional view of refractory lining with stave.

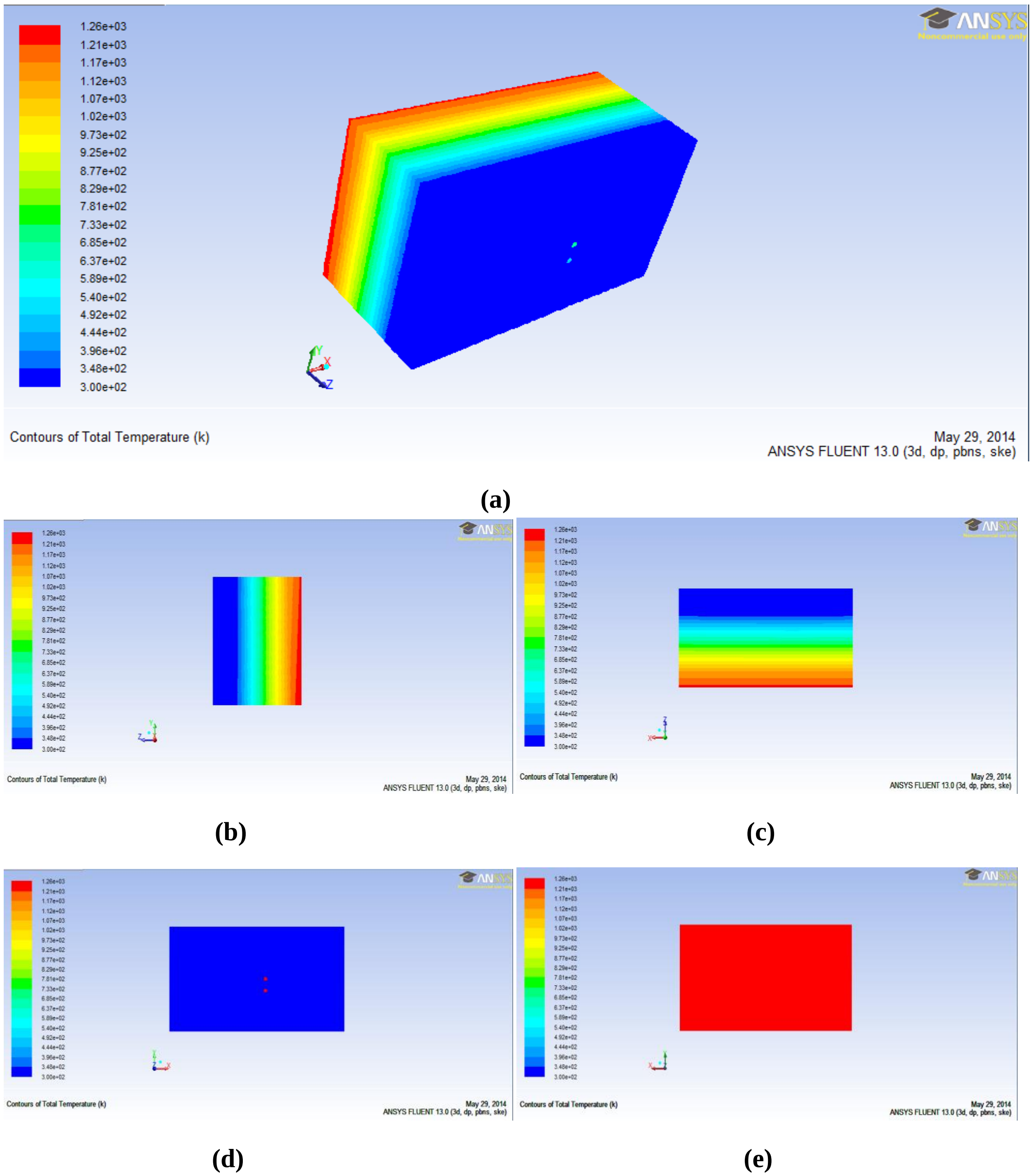


Figure 4.3 3D model of refractory lining (550mm) with stave cooler (a) Isometric view (b) Side view (c) Top view (d) Front view (e) Rear view

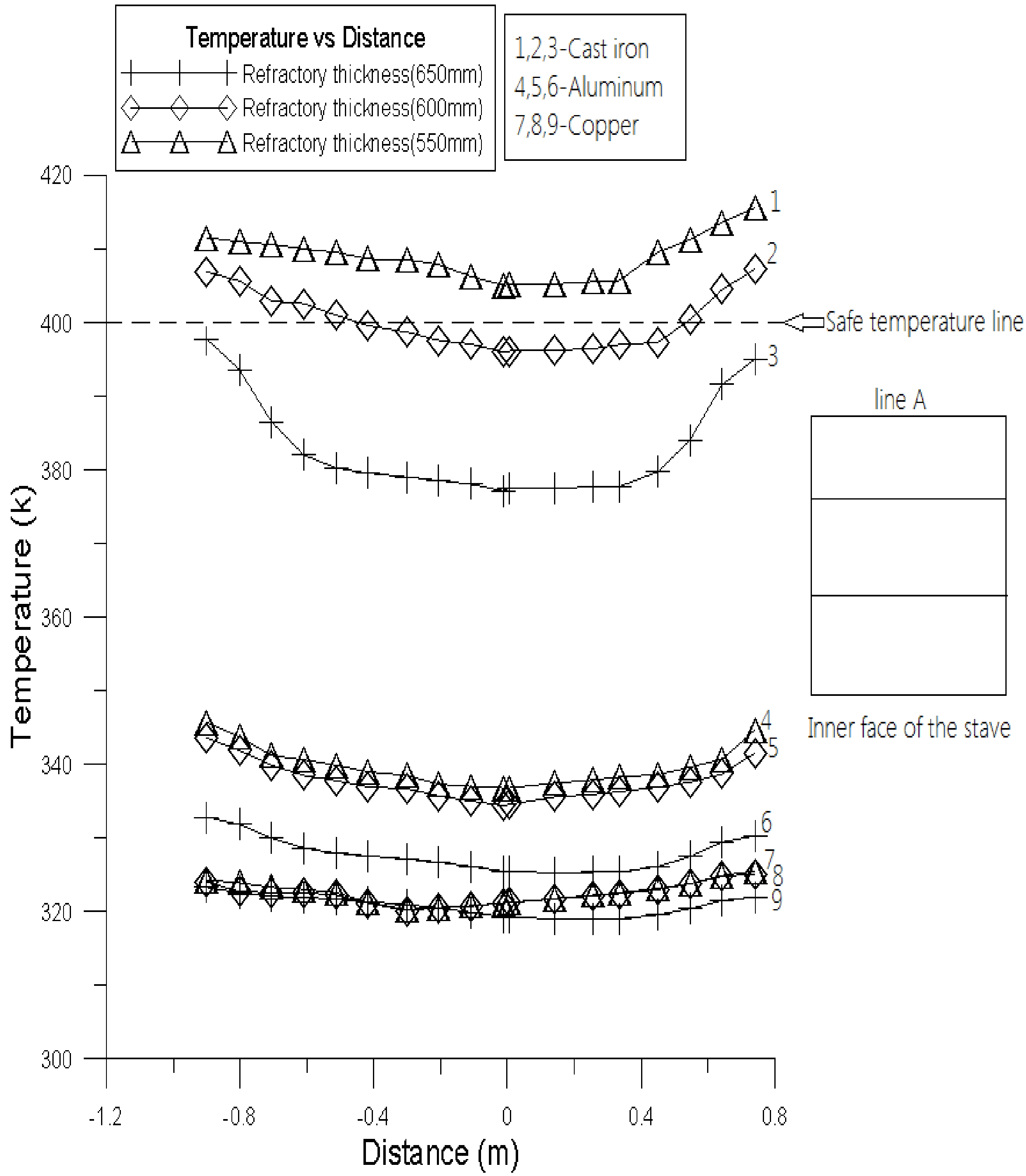


Figure 4.4 Temperature variations with distance for different refractory thickness with different stave materials at inner face of the stave (line A)

In this graph 4.4, we have analyzed the inner face of stave at line A by taking different stave material at different thickness of refractory material. When we take refractory thickness of 650mm having cast iron as a stave material temperature variation is found below the safe temperature limit, which is desirable. With decrease in thickness of the refractory material the temperature variation curve was found to increase. It also crosses the safe temperature limit, hence it is not desirable. At 600mm it was found fluctuating between safe and unsafe limit, and at 550mm thickness it was completely above the safe limit.

It can be seen in the curve that with increase in distance from the canter temperature remains constant for some time and then gradually increases at larger distance. It happens because cooling coil is present at the canter; hence more cooling occurs at the canter, but at the corner because distance is more, so cooling is less.

Similar pattern was also observed for aluminium and copper as a stave material but all below the safe temperature limit. Among the three materials copper was found to be the best material as compared to cast iron and aluminium. It is because very large amount of heat is dissipated by copper as compared to others.

We have also seen that as cast iron is very close to the safe limit, any reduction in thickness due to high heat generation causes severe damage.

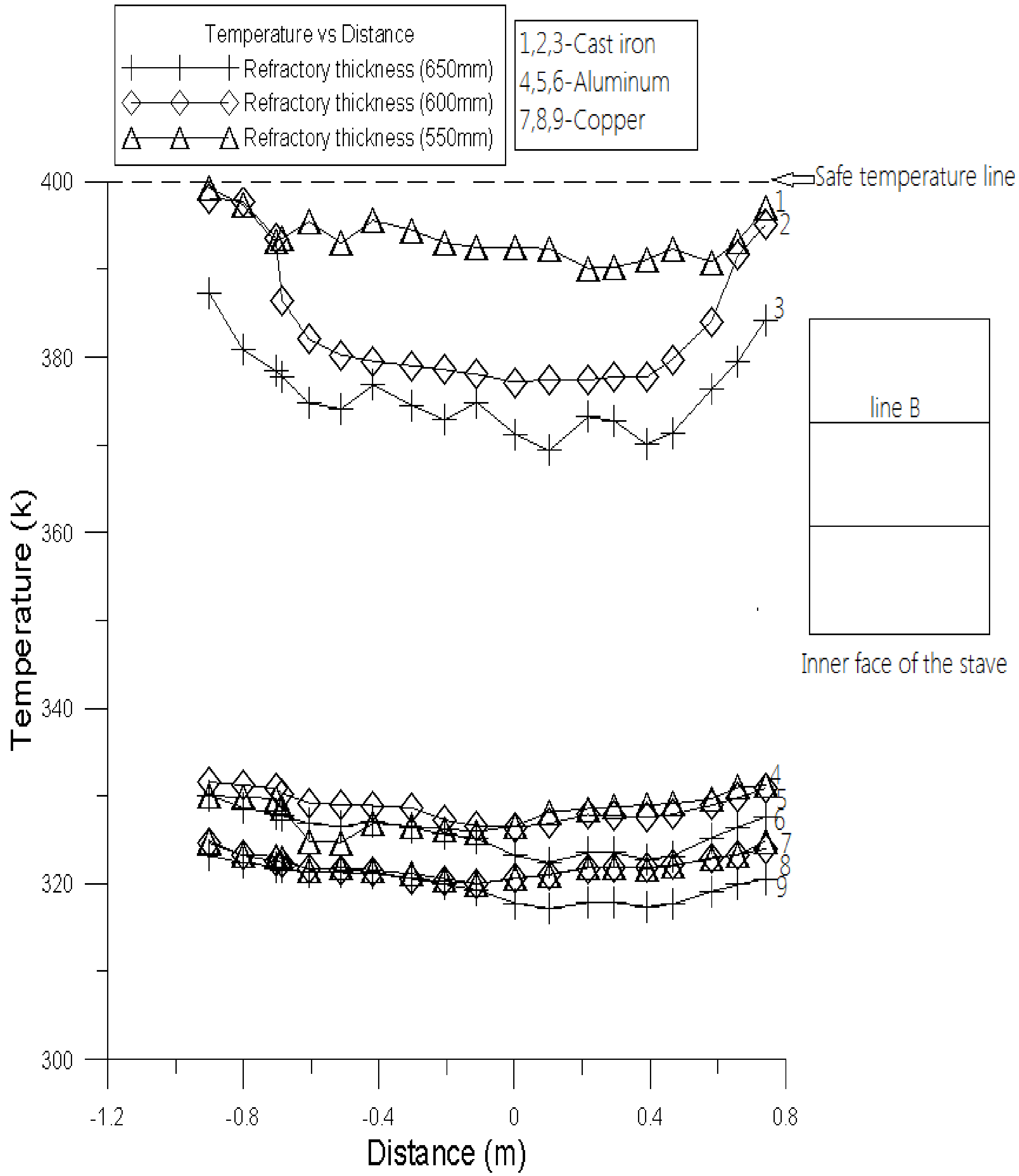


Figure 4.5 Temperature variations with distance for different refractory with different stave materials at inner face of the stave (line B)

In this graph 4.5, also we have analyzed the inner face of stave at line B by taking different stave material at different thickness of refractory material. In this case we found that temperature variation curve was always below the safe limit at any refractory thickness ranging from 550mm to 650mm. Here also we found the same pattern as line A .It was also observed that for aluminium and copper cooling effect is uniform throughout the stave.

For Aluminium and copper as a stave material, the temperature generation is found to be lesser than the safe limit because of more thermal conductivity of respective materials which releases the heat faster. We can observe from the graph that the thickness variation of refractory doesn't affect much in the temperature generation. So we conclude that it can sustain for long period of time because of less affect of thickness of refractory on temperature generation.

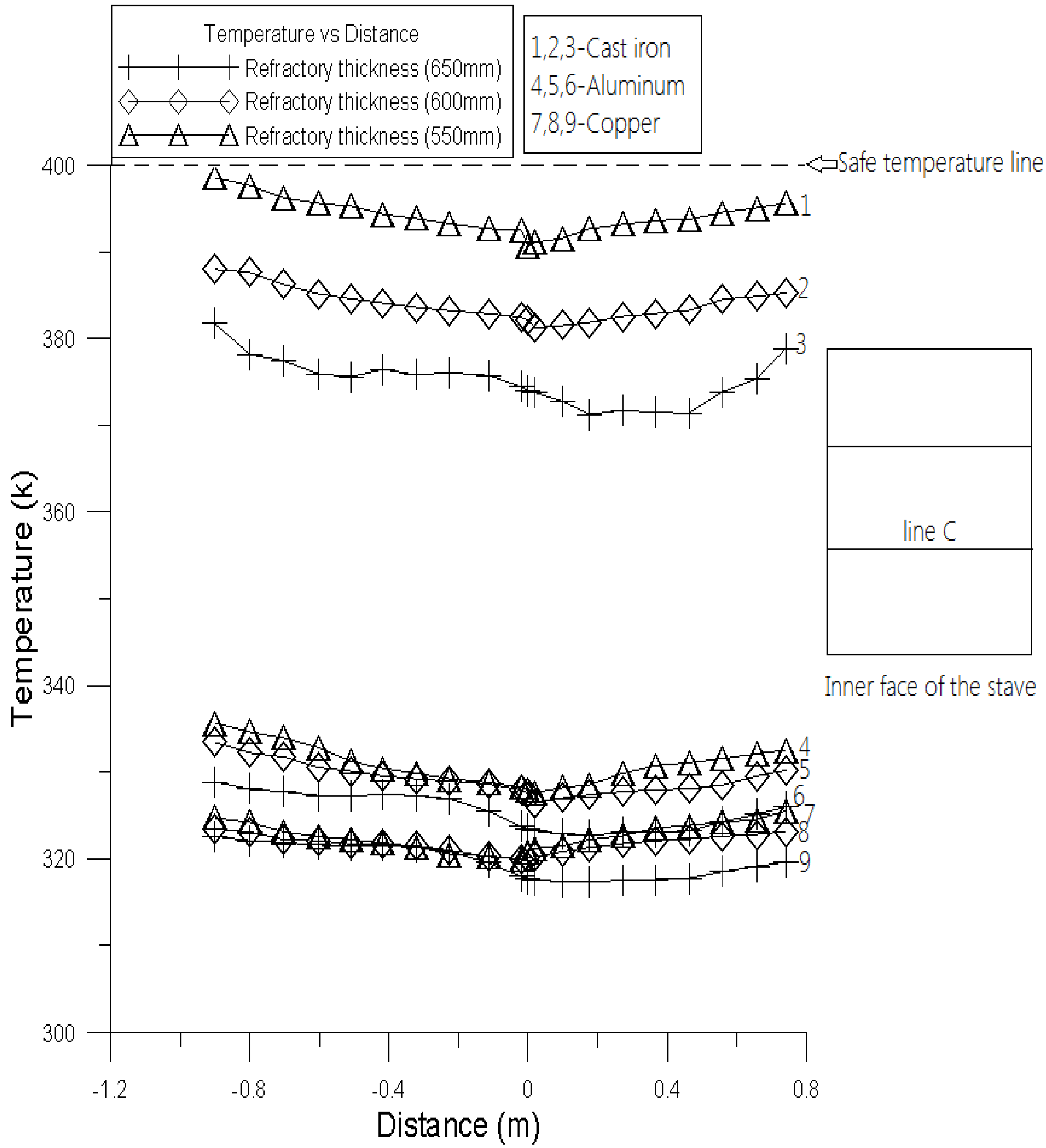


Figure 4.6 Temperature variations with distance for different refractory thickness with different stave materials at inner face of the stave (line C)

In this graph 4.6, we have analyzed the inner face of stave at line C by taking cast iron, aluminium and copper as stave material at different thickness of refractory material. In this case we found that temperature variation curve was always below the safe limit at any refractory thickness ranging from 550mm to 650mm.

For cast iron temperature variation curve was always below the safe limit because line C is near the centre of the stave and close to cooling coil, hence heat is dissipated quickly. All other patterns remain the same. With decrease in refractory thickness the temperature increases. But as cast iron thermal conductivity is less it is very close to the safe temperature limit, hence not very suitable for use.

For Aluminium and copper as a stave material, the temperature generation is found to be lesser than the safe limit because of more thermal conductivity of respective materials which releases the heat faster. We can observe from the graph that the thickness variation of refractory doesn’t affect much in the temperature generation. So we conclude that it can sustain for long period of time because of less affect of thickness of refractory on temperature generation.

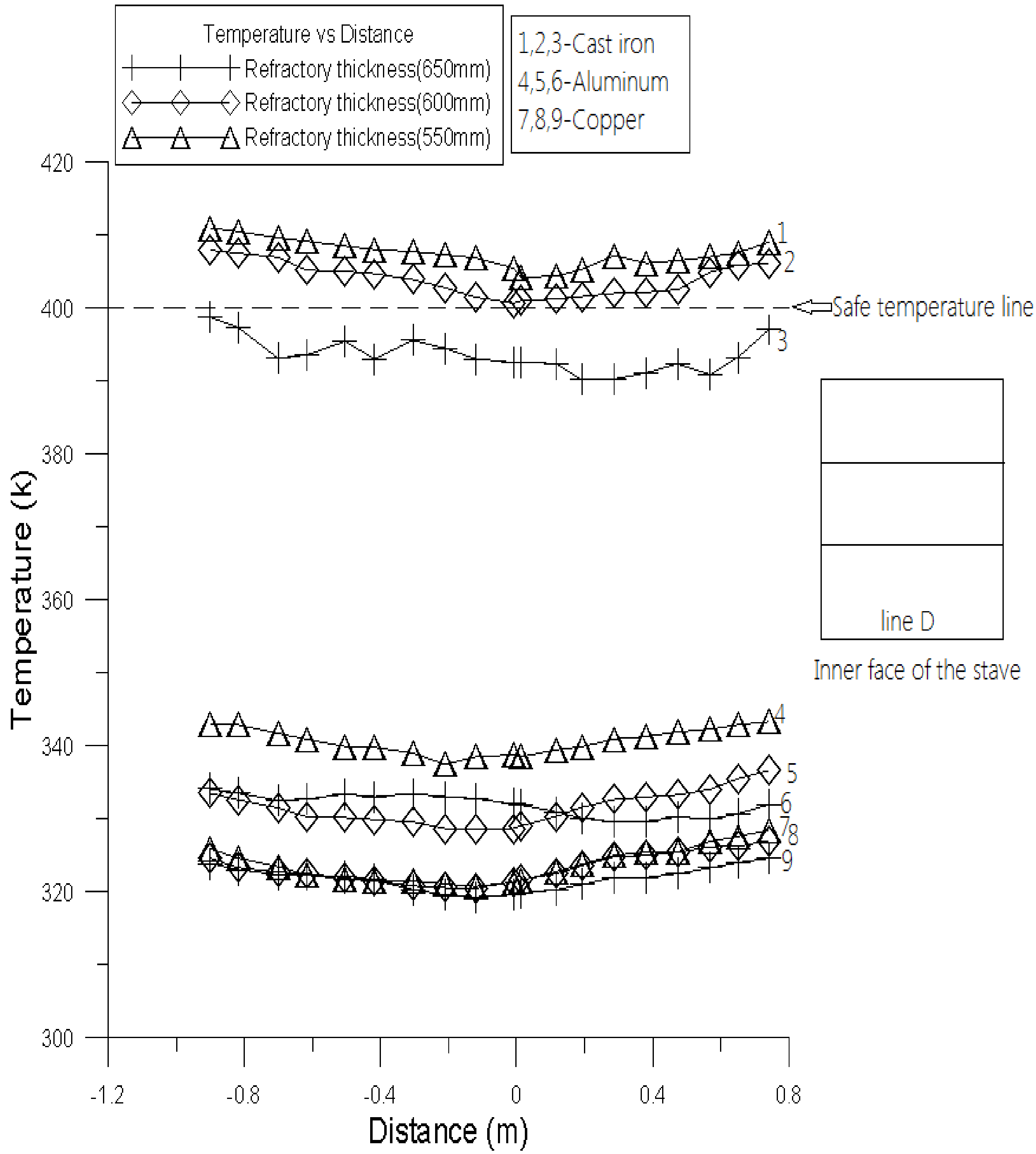


Figure 4.7 Temperature variations with distance for different refractory thickness with different stave materials at inner face of the stave (line D)

Similar pattern was also observed in case of line D. But as line D is far from the cooling coil heat dissipation is less. Hence we find that when refractory thickness is either 550mm or 600mm for cast iron temperature generated is above safe limit, which was not in the case of line C. But at 650mm it was found to be below safe limit due to large refractory thickness.

For aluminium and copper as usual their temperature variation is found below the safe temperature limit. Copper due to its higher thermal conductivity is more preferred material, because it was seen that temperature generated is least among all three materials.

Fig.4.8 shows the variation of temperature with increase in length of the coil when nitrogen and water is used as cooling agent for refractory thickness of 650mm. It was observed that same curve can be obtained if we increase the mass flow rate of nitrogen by four times as that of water, then same cooling effect can be obtained.

Here we see that with the increase in length, temperature increases slowly, while approaching the extreme end of the stave heat increases gradually. But the rise in temperature is rapid when it reaches the extreme corner of stave- refractory interface. The temperature slumps down suddenly while approaching the outlet. However, the gradual rise is observed when the cooling agent reaches the outlet. Finally, the outlet temperature is little higher than the inlet temperature due to heat absorption in the entire process.

Same phenomenon was also observed when we simulated on the refractory having thickness of 600mm as shown in Fig.4.9 and also for refractory having thickness of 550mm as shown in Fig.4.10

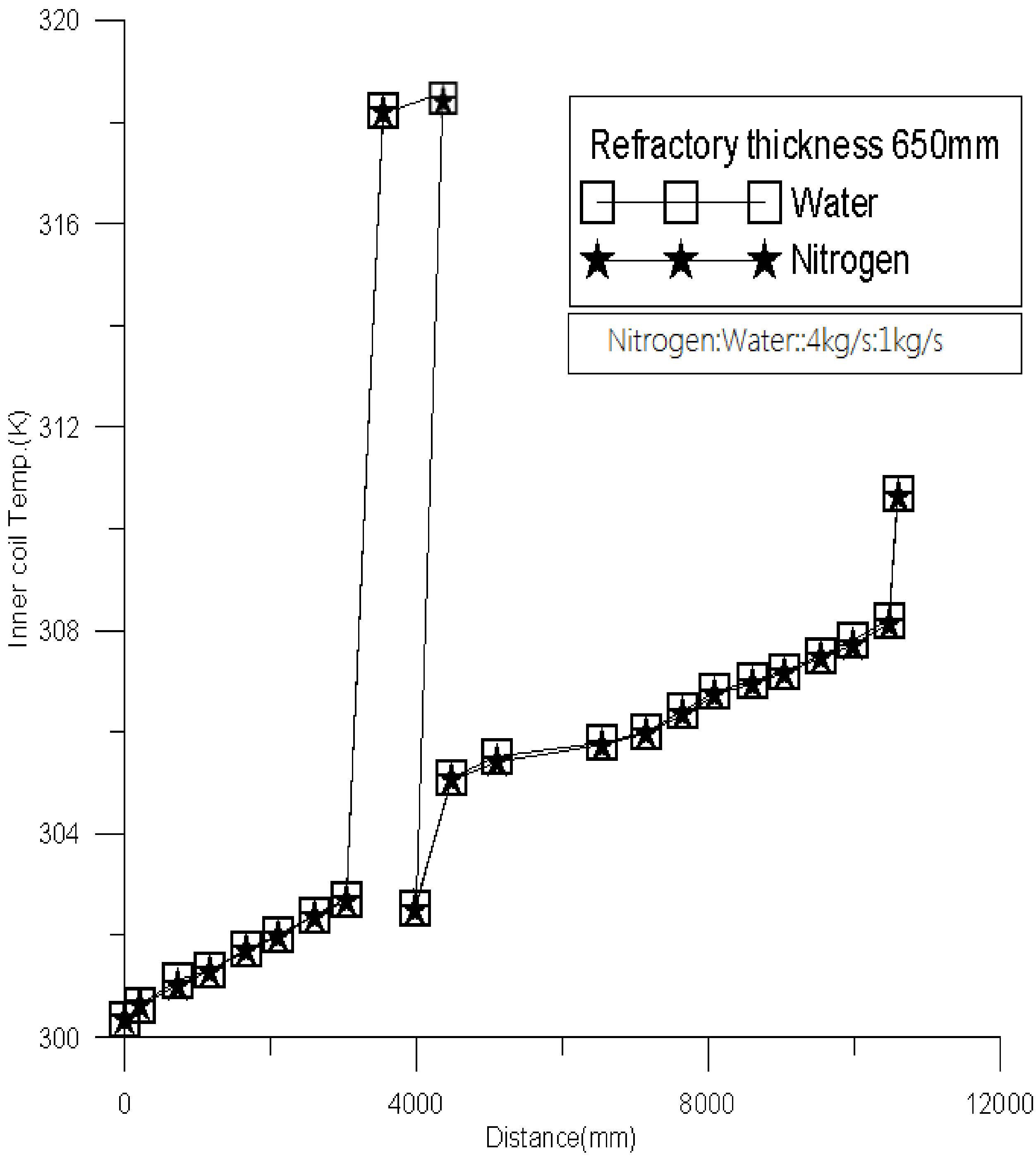


Figure 4.8 Inner coil temperatures versus distance (Refractory thickness 650mm)

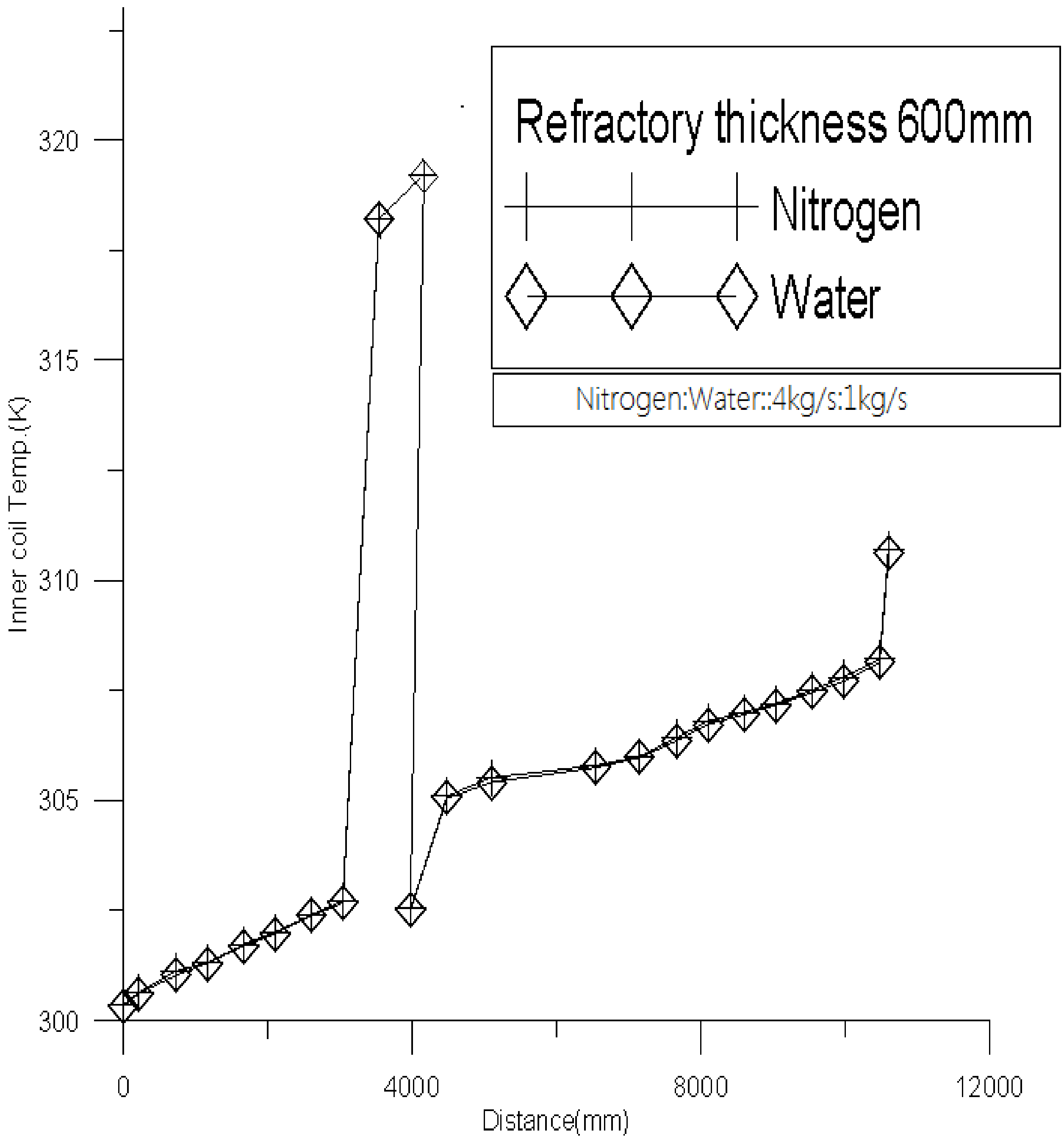


Figure 4.9 Inner coil temperatures versus distance (Refractory thickness 600mm)

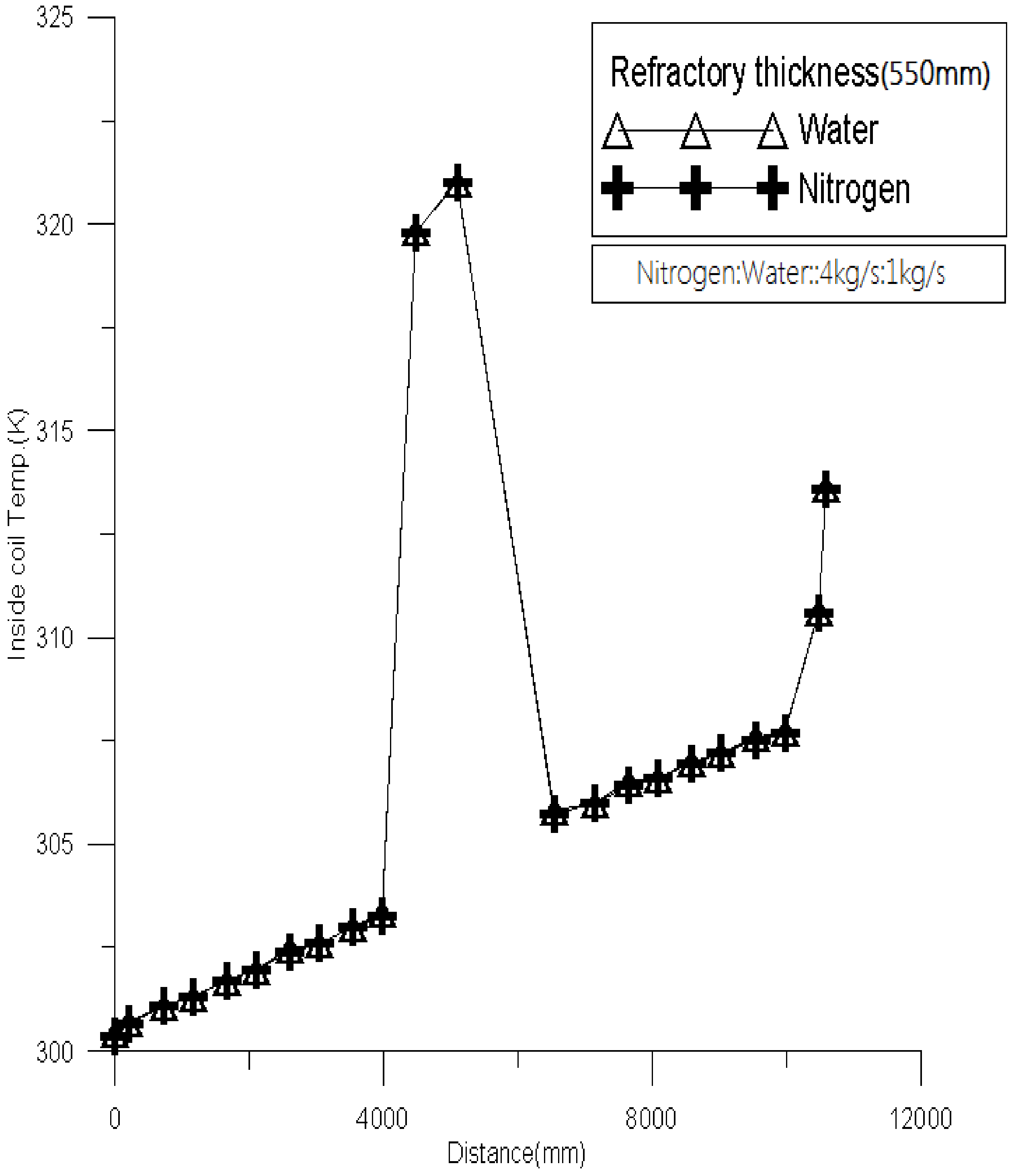


Figure 4.10 Inner coil temperatures versus distance (Refractory thickness 550mm)

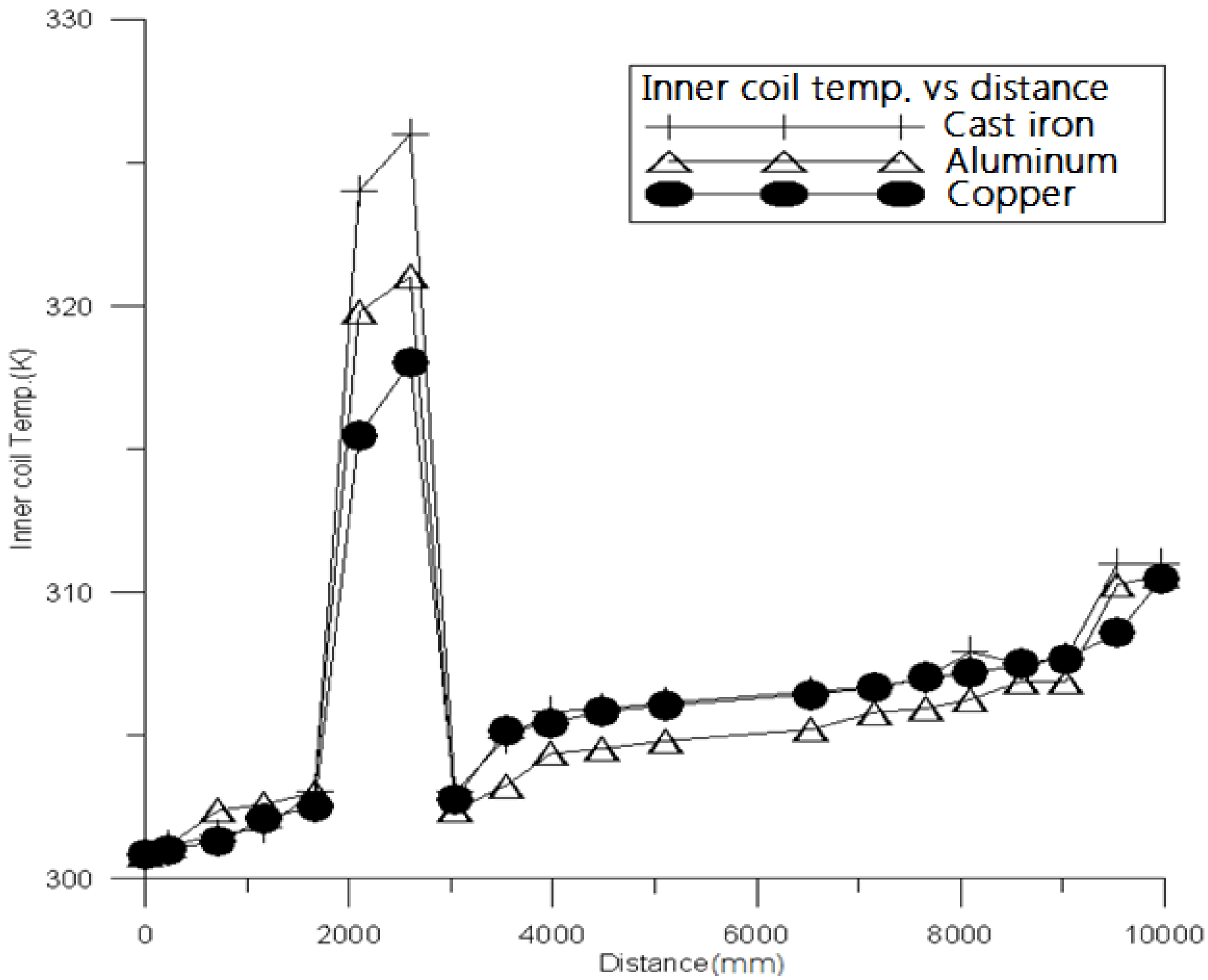


Figure 4.11 Inner coil temperatures versus distance

We have three materials viz. cast iron, aluminium, and copper are used as a stave materials. All the three are treated with water in order evaluate the temperature variations at a particular instant of length. The inlet temperature for all the three stave coils is given as 300 K. From the Fig.4.11; we observe that the outlet temperature for all the three stave coils is also equal. However, the Figure depicts a sudden rise at a particular point in all the three coils. We also observe that, the temperature rise is dominated in the case of copper coil followed by aluminium and cast iron coil respectively. This phenomenon is observed basically at the point nearer to the stave corner approaching the refractory lining.

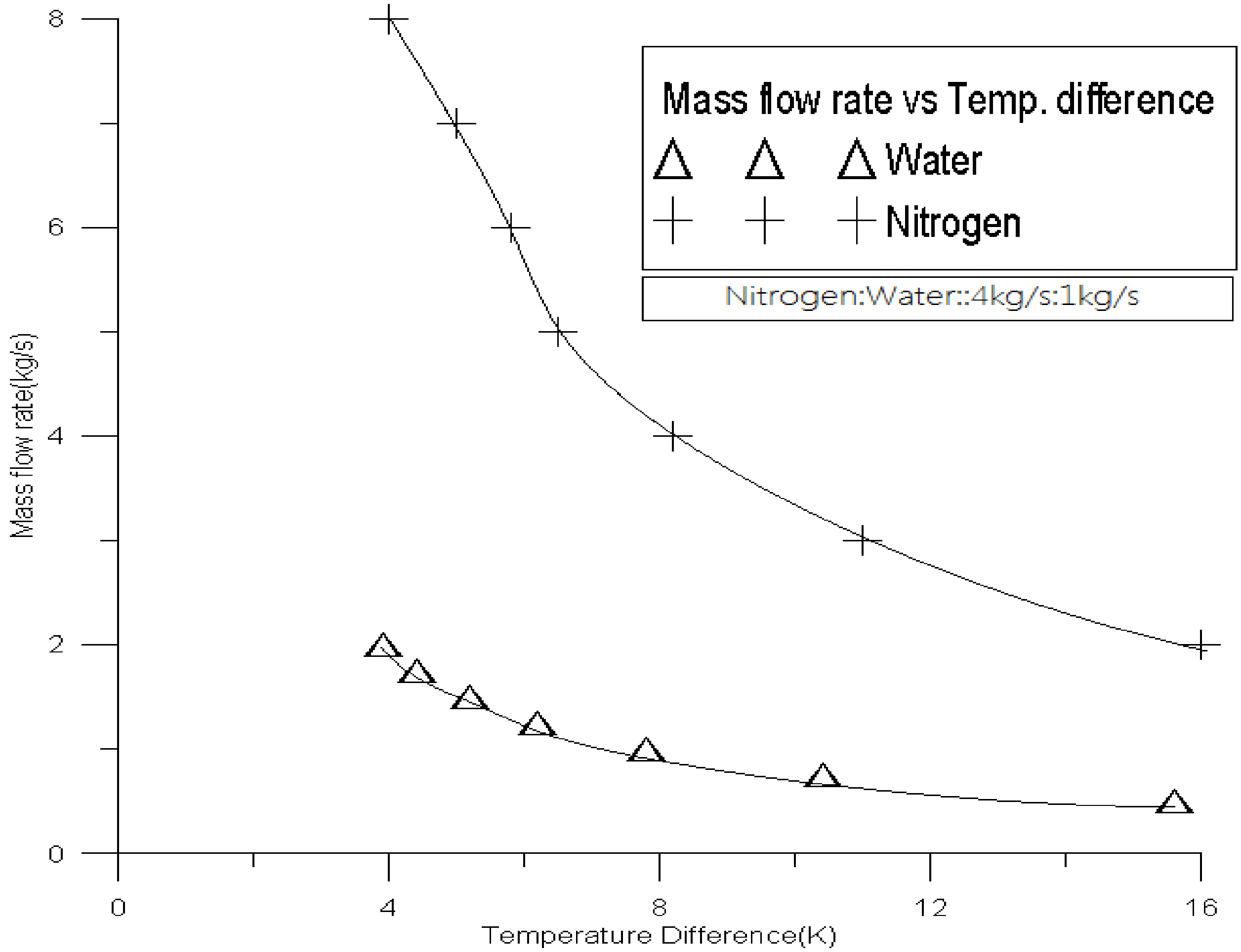


Figure 4.12 Mass flow rate versus Temperature difference

The Fig.4.12; depicts the relationship between mass flow rate of water and nitrogen in the coil with respect to the temperature difference. The quantity of nitrogen is taken four times than that of the quantity of water in this experiment. However, we observe that the temperature difference for both the cooling agents (water and nitrogen) varies in the similar manner.

CHAPTER 5
CONCLUSIONS

5. Conclusions

In present research work experimental and numerical analysis has been done for the refractory lining with stave cooler. Experimental result almost matched with numerical result. From the obtained results it can be concluded that:

1. If copper and aluminum is used in place of cast iron as stave material, the factor of safety of the stave material is greatly enhanced due to higher thermal conductuctivity. As a result, the stave will sustain for longer period i.e relining period of the refractory is increased. Also production is increased and the cost for relining and manpower is reduced significantly.
2. The temperature variation from the inner part of refractory lining to the inteface of stave-rafractory decreases linearly with respect to the instantaneous length.
3. By using the mass flow rate of nitrogen as four times than that of water, we get the desirable results as compared to water due to abundance of nitrogen in the industrial wastage.

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