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Design a Refractory Boiler Shell for Optimum Weight

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ABSTRACT

Now a day failure of refractory material in boiler furnace which is applied for different sites and different applications is the major problem has been faced by boiler manufacturing industries and they are trying to solve this. Different reasons of failure can be inappropriate transportation problem and loose application of refractory, excessive temperature developed in shell, sigma phase embrittlement, failure of anchors, improper storage of material etc. The materials and its properties used for refractory are studied here with its different types. This report is related to thermal and structural analysis of refractory which is 75 mm thick and temperature distribution at certain distance by using ANSYS software.3D Model is drawn in solid works and then imported to ANSYS for next analysis. By applying thermal and structural conditions we get the results.

Keywords: *Refractory design, Boiler, thickness, stresses*

I. INTRODUCTION

The refractory inside the boiler furnace is an important structure to safeguard the boiler structure and to increase the efficiency of its operation. Refractory is material that retains its strength at high temperatures and non-metallic materials having those chemical and physical properties that make them applicable for structures, or as components of systems, that are exposed to environments above 1,000 °F (811 K; 538 °C).The applications of refractory materials are for furnaces, kilns, incinerators, and reactors. Where the temperature is to high to bare by material refractories are applied at such conditions to protect from getting damaged or burst. The material used in industry is of different types for different boiler as per temperature requirement. For this case castable refractory's are used. Refractory structures used in power boilers use stainless steel anchors for reinforcement. Failure of refractories in the form of cracks leading to falling off them was observed in operation. Often the refractory's themselves are not the cause of failure rather the reinforcing metallic anchors were found to be the one. Wrong choice of material, inadequate design of refractory structure, over temperatures leading to anchor material deterioration, are among the main reasons for anchor failures. The reason of refractory failure mostly due to transportation problem, as well as excessive temperature inside the furnace is observed.

Fig.1 Different Forms of Refractories

Some Important properties of refractories are: chemical composition, bulk density, apparent porosity, apparent specific gravity and strength at atmospheric temperatures. These properties are often among those which are used as „control points" in the manufacturing and quality control process.

II. Literature Survey:

C.Soupramanien et al states that the present study analyse the refractory structure failure in the bull nose - hot face area of cyclone. Failed anchor rods made of AIS309 SS were analyzed. Sigma (s) phase induced embrittlement caused failure of anchor at the non-welded end. At the anchor-MS plate weld, poor quality of the weld was noted. Overheating from flue gas entry in the gaps caused by inadequate expansion joints resulted in damage to the backup insulation layers. At such high temperatures, the SS anchor-MS weld will have a lesser strength and weld failure occurred. Loss of anchor reinforcement resulted in falling of refractories.

Mohammed Qazam Naser et al states that A pressure vessel is a container used to contain things at higher pressure this means that if can withstand greater than normal amounts of pressure without bursting. Pressure vessels are used to contain a multitude of things, including air, water, chemicals, nitrogen, and fuel. They are used in paper and pulp, energy, food and beverage, and chemical industries. Since the pressure in the vessel is high, it has to with stand both thermal as well as structural. The aim of this project is to design a pressure vessel whose sole purpose is to withstand the pressure of the substance stored in it. Modeling has been done in Pro-E modeling software and analysis is done using ANSYS. The dimensions of the vessel have been arrived by analytical calculations as per ASME standards. Finally the design calculations and the values obtained by analysis are compared to do the final design. The above results are verified in software by using ANSYS-14.5. The pressure vessel is analyzed for the thermal loads, pressure loads and combined pressure as well as thermal loads, also analyzed for induced stresses to show that the developed stresses and temperatures are within the controlled values.

D.Kondayya (2016): This paper described the structural and thermal analysis of steam boiler. The main considerations in the design of a boiler for a particular application are Thermal design and analysis, Design for manufacture, physical size and cost. In the present paper a fire tube boiler is analyzed for static and Thermal loading. The geometric model of boiler is created in Catia v5 software as per the drawing. This model is imported to hypermesh through iges format and FEA model with converged mesh is developed using shell elements. To this FEA model various loading conditions like design pressure, thermal loads and operating conditions are applied.

V. Ashok Kumar (2016): In this paper the steam flow in steam boiler tubes is modeled using PRO-E design software. The paper will focus on thermal and CFD analysis with different velocities (25, 30, 35& 40m/s).Thermal analysis done for the steam boiler by steel, stainless steel& brass at different heat transfer coefficient values. These values are taken from CFD analysis at different velocities. In this thesis the CFD analysis to determine the heat transfer coefficient, heat transfer rate, mass flow rate, pressure drop and thermal analysis to determine the temperature distribution, heat flux with different materials. 3D modeled in parametric software Pro-Engineer and analysis done in ANSYS.

Anandhu P. D (2017): This project deals with design and analysis of horizontal pressure vessel and also thickness optimization of vessel. Pressure vessel is a container for confining fluid at elevated temperature and pressure. In the design of pressure vessel safety is the primary consideration, due the potential impact of possible accidents. Efforts are made in this project to design the pressure vessel using ASME codes & standards to legalize the design. Here we design the pressure vessel with ASME Section VIII, Division 1,2013.Finite element analysis of the pressure vessel has been done in ANSYS. Static structural analysis of the vessel has been done by applying the internal pressure, standard earth gravity, and also by fixing both the legs. Thickness optimisation of the pressure vessel is also done in ANSYS.

D. Kondayya states that steam boiler is a closed vessel in which water or other fluid is heated under pressure and steam which is released out by the boiler is used for various heating applications. The main considerations in the design of a boiler for a particular application are Thermal design and analysis, Design for manufacture, physical size and cost. In this paper a fire tube boiler is analysed for static and Thermal loading. The geometric model of boiler is created in CATIA V5 software as per the drawing in 2D. This model is imported to HYPERMESH through IGES format and FEA model with converged mesh is developed using shell elements. To this FEA model various loading conditions like design pressure, thermal loads and operating conditions are applied for solution. One of the supporting legs is arrested in all the directions and the other one is arrested only in X, Z-directions and all rotations. All these are created by using HYPERMESH and it is exported to ANSYS for solution to obtain the deflections, stresses. Those values that are obtained are correlated with material allowable values as per the ASME Section VIII Division 2.

Y. Venkat et al states that this paper discusses an improvement in shell refractoriness and dimensional stability of columnar grained (CG) low pressure turbine blade castings which is made up of Ni base superalloy by directional solidification process (DS). Two ceramic shell systems were adopted, called shell system I and II. Shell moulds were prepared by using ceramic slurries containing zircon flour as a filler material and colloidal silica as a binder. As compared to shell system II (zircon filler with colloidal silica binder and fine alumina), shell system I (zircon filler with colloidal silica binder) showed lower refractoriness. Shell system II showed flexural strength increases in both the green as well as in fired conditions. Shells made from shell system II showed about 13% higher green strength and 55% higher fired strength as compared to shell system I. Shell system II also exhibited superior self sag resistance up to 1625°C. Moulds prepared from this shell system yielded aeronautical grade casting with high dimensional accuracy even at a metal pouring temperature of 1550°C. Moulds from shell system I, on the other side underwent sagging even at metal pouring temperature of 1500°C, which leads to dimensionally unacceptable castings. The superior performance of shells prepared from shell system II can be ascribed to the presence of fine alumina in the shell.

Braimah (2017): In this paper described the boiler is the device in which steam is generated by applying heat energy to water. Generally, a boiler consists of water container and some heating devices. To generate steam, the steam boiler is subjected to huge thermal and structural loads. The objective of the paper is to perform a 3D model and stimulate the boiler using ANSYS software to determine the loads and deflections on it. To obtain maximum efficient operation condition of the boiler, it is important to design a structure that can withstand the operating conditions of the thermal and structural loads on the boiler. ANSYS Workbench Model NX 8.0 was used to design the 3D model and also used for the analysis. The modeling process includes the static structural analysis, steady-state thermal analysis and modal analysis. The activities in the ANSYS modeling was categorized into three processes, namely, the preprocessor, the solution and the post processor. Generation of the model was conducted in the preprocessor, which involves material definition, creation of a solid model, and the meshing. In the solution stage, analysis type was defined and the boundary conditions were specified and the solution was done. The results were generated from the post processor stage. From the analysis, it was concluded that the steam boiler has stresses and deflections within the design limits of the material used. Hence, the designed steam boiler is safe under the given operating conditions. The result obtained shows a maximum tensile stress and deformation of the boiler as 308.90 MPa and 1.93 mm respectively. From the results, the tensile stress obtained is below the yield strength of the material used, which makes it safe for operation under those conditions.

S. Anjani Devi (2017): In this paper worked on boiler or steam generator, It is a closed component in which fluid is converted into steam by heating under pressure. Thus steam produced from a boiler has many practical applications. The design considerations such as physical size, materials, cost and Thermal specifications of a boiler vary with applications. The aim of this thesis work is to develop optimized boiler to preserve temperature & pressure more efficiently; generally boiler are made with Mild Steel (MS) / Stainless steel with coatings according to the conditions; in this project MS with reaper and dual shell will be analyzed. Coupled field and fatigue analysis will be conducted on plain reaper (empty), & with filler materials to work as insulation layer; in coupled field analysis thermal and structural loads will be analyzed at a time to fine stress, strain, and flux in dual load conditions. Fatigue analysis will be done to determine maximum life/ fatigue behavior.

Prashant Singh(2017): This paper reviews some of the developments in the determination of stress concentration factor in pressure vessels at openings, stress analysis of different types of end connections and minimization stress with the help of optimize location and angle of nozzle on shell and head. The motivation for this research is to analyze the stress concentration occurring at the openings of the pressure vessels and the means to reduce the effect of the same. Design of pressure vessels is governed by the ASME pressure vessel code. The code gives for thickness and stress of basic components, it is up to the designer to select appropriate analytical as procedure for determining stress due to other loadings. In this paper the recent and past developments, theories for estimation of stress Concentrations are presented and the scope for future studies is also presented.

Kothakranti Kumar (2016): This paper focus on understanding the best combination of material to be used for a low capacity power plant boiler shell; a comparative study has been done which includes two different materials, a conventional material (SS301) and Functionally Graded Material (WC-SS) is implemented. The work involves modelling the basic structure of boiler shell and the analysis phase involves the study of the structural, thermal and vibrational outputs for both the materials. The analysis would highlight the advantages in change of material while keeping the same shell thickness.

H. R. Aher (2015): This paper states that expansion joint have a function to absorb regular or irregular expansion and con-traction in piping system, it is widely used as the element of expansion joint in various piping system, aerospace, micro electromechanical and industrial system. Most industrial piping system often suffer excessive deformation, displacement, heat expansion, vibration, and other causes are responsible for the failure. The main issue is to verify that there are various deformation stresses which is build due to various factor in pressure vessel such as thermal stress, internal pressure etc. and check whether there is requirement of expansion joint to reduce those stresses.

Sencha (2016): In this project, finite element analysis is conducted on the boiler shell with riveted joints using composite materials for its strength. The 3D modelling of the boiler shell is done in Pro/Engineer. Static analysis, modal analysis is performed and compared for different materials steel, aluminium alloy, composite materials CFRP by using solid element. Analysis is also conducted using composite materials using shell element. Analysis is done in Ansys.

Heru Susiawan Widiharso (2017): This paper researched on design parameter optimization based on finite element method (FEM) simulations is presented here. The aim of this paper is to perform the detailed design & analysis of pressure vessel for optimum thickness using finite element method based commercial software ANSYS. Several geometrical models of pressure vessel are proposed and compared by optimization method. The diameter and the length of the pressure vessel are varied. It is shown that a direct optimization gives the minimum weight of pressure vessel with optimum wall thickness. The optimized pressure vessel is able to carry the internal load with same safety factor but lower weight compared to the existing model.

III. Methodology

The methodology followed is as follows:

1. Create a 3D model of the boiler shell assembly using CATIA software.
2. Convert the surface model into Para solid file and import the model into ANSYS to do analysis.
3. Perform thermal analysis on the boiler shell assembly for thermal loads.
4. Perform static analysis on the existing model of the steam boiler assembly for pressure loads and thermal loads to find deflections and stress, optimized if enquired.
5. Based on the above results, design changes are implemented to reduce the stresses and deflections.

There are four component of model:

1. Stainless steel shell: Stainless steels are iron alloys with a minimum of 10.5% chromium. Other alloying elements are added to enhance their structure and properties such as formability, strength and cryogenic toughness.
2. Fiberfrax paper or Ceramic Paper: The Fiberfrax ceramic fiber paper product line is a unique family of products which is manufactured by forming alumin silicate fibers in a nonwoven matrix. The ceramic fibers are randomly orientated during manufacture, then held in place with a latex binder system. A specialized paper-making process is statistically controlled to form uniform, lightweight, flexible sheets.
3. RefractoryFerrule: Refractory ferrules are designed to protect boiler tube inlet areas and metal tube sheets in sulfur recovery units (SRUs) used in oil refinery operations. Boiler tube inserts

are also used in methane reformers and waste heat boilers (WHB). Refractory ferrules are made of materials called refractories that have high melting points. Refractories are suitable for applications requiring wear resistance, high temperature strength, electrical or thermal insulation, and other specialized characteristics. Alumina is a commonly used refractory material in boiler tube ferrule applications. Alumina's chemical inertness and resistance to hydrogen sulfide protects the tube sheet inlets and tube sheets from hot sulfur gas corrosion. Other materials used in refractory ferrules and boiler tube inserts include silicon carbide and zircon, which may or may not be matrixed with alumina.

4. Alignment Sleeve: The alignment sleeve is located in the through connector, and is used to align the ends of 2 ferrules so that the cores of the 2 fibres are aligned. Alignment sleeves for single mode fibre are generally made from beryllium copper or ceramic.

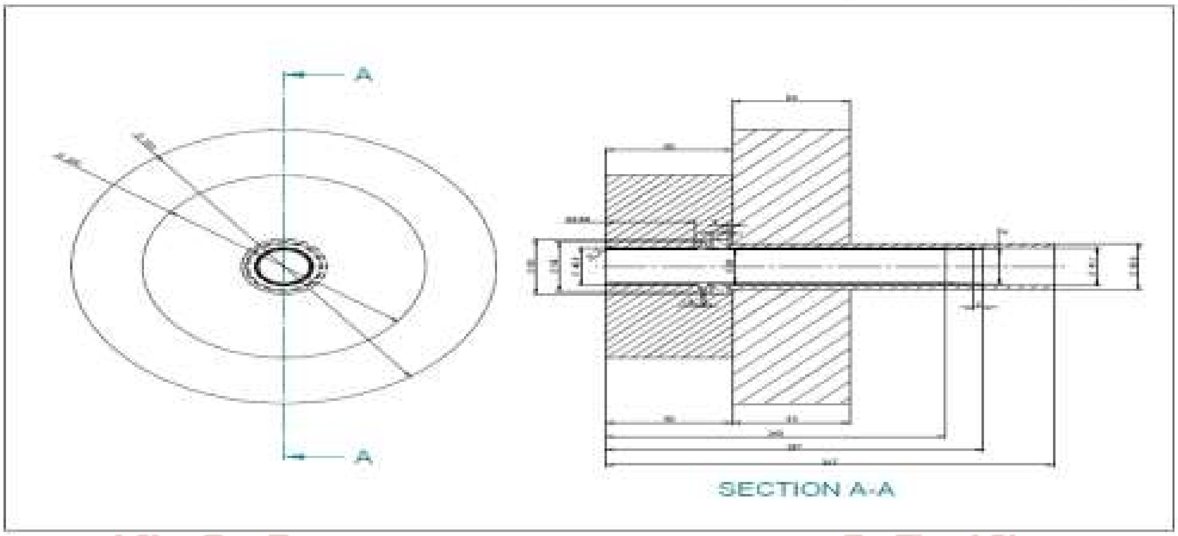


Figure 1: 3D model made in Catia v5

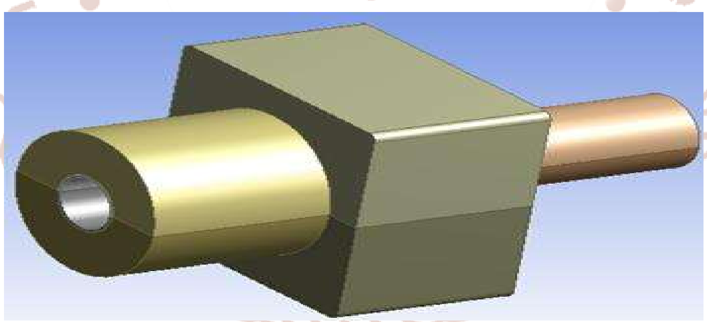
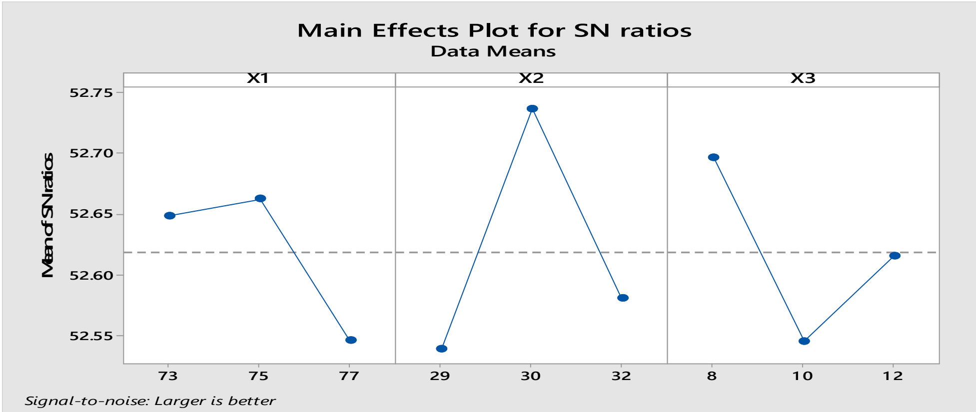


Figure 2: 3d model of boiler shell

IV. Results

Analysis is done using Minitab and optimum parameter are observed. Following Table1 shows parameters and their levels:

Symbol	Parameters	Units	Level 1	Level 2	Level 3
A	Thickness	mm	73	75	77
B	Thermal Conductivity	w/mk	29	30	32
C	Steam Pressure	Pascal	68947.6	55158.1	82737.1



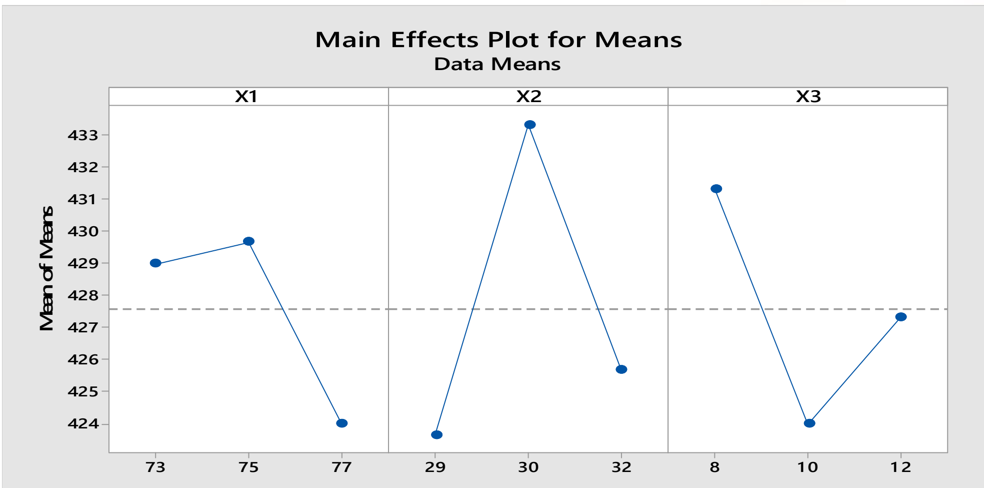


Table2 shows Layout of L_9 Orthogonal array

A	B	C
1	1	1
1	2	2
1	3	3
2	1	3
2	2	1
2	3	2
3	1	2
3	2	3
3	3	1

V. Conclusion

Paper can be concluded as:

- The static and structural analysis is done by using Ansys 14.5 for three different materials.
- The Taguchi Method is used for calculating optimum thickness and is 75mm.
- Thermal Analysis is done by using Ansys software for surface temperature analysis.
- Reason for refractory failure is found out and it is due to the thermal imbalance & improper temperature distribution.
- The surface temperature calculated is 415.1ºc.

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