Failure Analysis of a Steam Pipe Used in Rotary Kiln Under High Temperature Conditional Circumstances

Vijayan.S.N, T.Gunasekaran, SenthilKumar.K.R

Abstract--- The high temperature Steam Pipes used in Rotary kiln is to activate charcoal in activated carbon industry. High temperature Steam is the heart of activation process which is continuously and uniformly distributed in the activation zone. Aim of this study is to analyze the fracture produced in the steam pipe in heat affected zone during the process. Analysis was performed in two types of pipes such as pipes having straight holes and without holes using finite element analysis method. Total deformation, equivalent stress and temperature distributions were determined to analyze the failure.

Keywords: Rotary Kiln, Failure Analysis, Steam Pipe, Deformation, Equivalent Stress.

1. INTRODUCTION

The rotary kiln is a horizontal circular cylinder lined with refractory material supported by support stations and driven via a girth gear and drive train. Rotary kilns can be described as Calcinations devices that facilitate chemical or physical transformations by subjecting materials to very high temperatures [1,2]. High temperature steam is used in rotary kiln to activate charcoal in activated carbon industry [3], steam pipe is inserted in the kiln under high temperature conditional environment. The Kiln could be divided in to three working zones in first zone temperature would be approximately from 550^{O}C and second and third zone were 750^{O}C and 900^{O}C respectively. A temperature range of 400^{O}C and 850^{O}C was found to be the carbonization temperature, though it may sometimes reach up to 1000^{O}C while activation temperature between 600^{O}C and 900^{O}C [4]. To maintain this temperature, high pressure steam must be continuously supplied on the material during the process. The Pipe must be kept inside the kiln during the process which causes to generate fractures in steam pipe due to the self weight, external and internal condition also which affect the life of the pipe and quality of product [5]. The main steam pipe system containing high temperature and high pressure steam is one of the weakest links in pipeline system [6]. Various analyses were made in steam pipe used in different applications in that effect of Creep was analysed for P22 material using software for elastic analysis [7]. Mechanical behavior and failure pressure of the pipeline with single inner corrosion defect, multiple interacting inner corrosion defects and multilayer structural inner corrosion defect, von mises stress distribution of corrosion defects were investigated by nonlinear finite element method [8]. Fracture characteristics of pressured pipe line with crack using boundary element method were analysed and crack analysis of a thin tube was performed using finite element simulation [9,10].

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2. PROBLEM DEFINITION

Steam pipe was the heart of a rotary kiln for the process of materials for chemical reactions, and product quality would be varied depends on the applying steam pressure and quantity. The pipe must be kept inside a rotary kiln for the whole period, due to this the pipe might be getting damaged or fractured in the heat affected zone, even the pipe has been take out and cleaned periodically for every 12 hours. After some period the pipe was getting fractured in maximum heat affected area which is shown in figure 1 & 2.

Fig.1 Steam Pipe used in Rotary Kiln.

Fig.2 Damaged pipe

3. MATERIALS AND METHODS

A Stainless steel pipe was used for supplying high pressure steam with one end closed and other end is connected with outlet steam line from a boiler which is shown in figure 3. Initially, the pipe was analyzed in static condition without supplying steam by considering self weight and second the pipe was analyzed with straight holes made on the pipe from closed end, approximately 90 holes, 100 holes and 120 holes**.** Finally, the pipe with zigzag holes was analyzed with same number of holes which made in the straight holes. Total deformation, temperature distribution and equivalent stresses were calculated only for the pipes having without and with straight holes.

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4. DESIGN SPECIFICATIONS

The Pipe has 5650mm span with 46 mm outer and 38mm inner diameter, thickness of pipe was 4mm and hole diameter is 2.7mm which is made on the pipe from its end with an interval of 1 to 1.5 inches.

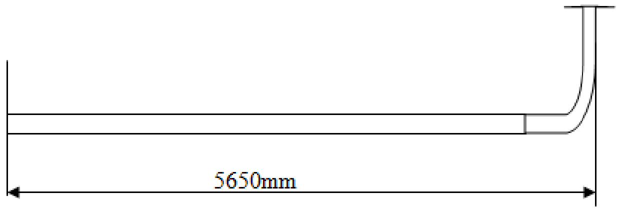

Fig.3 Steam Pipe

5. ALLOWABLE WORKING PRESSURE

The allowable working pressure of steam pipe can be determined by using equation 1. Allowable working pressure value was used to decide the maximum input steam pressure

$$P = \frac{2(S \times Eq) \times t}{(Do - 2Yt)} \quad (1)$$

Where
E_q=quality factor.
S=Allowable stress at design temperature, psi
t = specified wall thickness
Y = coefficient
Do = outside diameter

For static analysis need to consider loads such as static load, sustained load, wind load and thermal loads. In this work thermal load might be neglected because the working atmosphere was in closed condition. While considering static load assume that pipe as straight beam and carrying uniformly distributed load. Sustained loads were caused by mechanical forces during normal operation of the system which includes weight and pressure loading. Pipe weight, fluid weight and insulation weight can be determined using following equations 2, 3 & 4.

$$\text{Pipe Weight} = \frac{\pi}{4} \rho_{steel} \times (Do^2 - Di^2) \times \frac{g}{g_c} \quad (2)$$

$$\text{Fluid Weight} = \frac{\pi}{4} \times \rho_{fluid} \times (Di)^2 \times \frac{g}{g_c} \quad (3)$$

$$\text{Insulation wt.} = \textit{Insulation factor } x\ \rho_{Insulation} x\ g/g_c \quad (4)$$

Where
D_0 = Outside diameter of pipe, in
D_i = Inside diameter of pipe, in
t = Insulation Thickness depend on the NPS, in
g = Acceleration due to gravity, ft./sec2
g_c = Gravitational constants, lbm-ft/ft-sec2
ρ_{Steel} = Density of steel, ib/in3
ρ_{fluid} = Density of water, ib/in3
ρ_{insul}= Density of Insulation, ib/in3

Static load of pipe can be calculated by using below equation 5.

$$S_L = \frac{PD_0}{4t} + \frac{0.75i \times M_A}{Z} \quad (5)$$

6. THERMAL LOADS CALCULATIONS

The Pipe will be installed at ambient temperature which carrying hot fluids like steam and they expand especially in length when increasing temperature from ambient to working temperature which produced stress across the areas within the distribution system. The Fracture could be generated when the stress level increased maximum. The amount of expansion is calculated using the following expression.

Expansion (mm) = α × L ×Δ T
Where
ΔL = Length of pipe (m)
T = Temperature difference between ambient and operating Temperatures (°C)
α = Expansion coefficient (mm/m °C) x 10^{-3}

Thermal stress of pipe for three zones were calculates using equation 6.

$$\sigma_t = \alpha \times L \times \Delta_T \quad (6)$$

σ_t – Thermal Stress

α – Expansion Coefficent $(\frac{mm}{m^0C}) \times 10^{-3}$

L – Length of pipe

Δ_T – Temperature difference between ambient and operating temperature

7. RESULT AND DISCUSSION

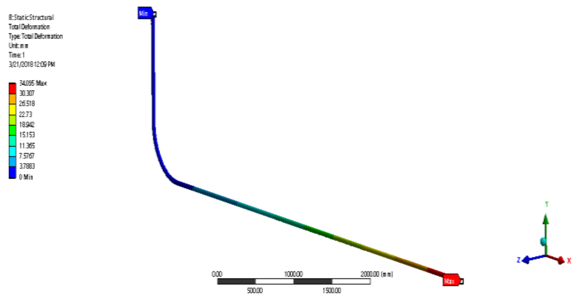

Fig.4 Deformation of steam pipe without hole

The figure.4 shows total deformation of a pipe without holes with static structural condition, while injecting steam at 12 psi pressure which is directly hit the end point of the pipe, which generates impact stress on the third portion of steam pipe. High level deformation produced in the end portion of the pipe having maximum value of 34.095mm. Primary reason for the deformation is the pipe was supported only in the inlet point. The deformation level of pipe would be varied based on the steam pressure also it's increased gradually from the starting segment of pipe to the end segment.

The figure.5 shows the total deformation of pipe with holes at same condition. In this pipe deformation level is high when compared with pipe having without holes because of high pressure steam ejecting through the holes

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continuously. Highest deformation occurred in the end portion of pipe having maximum value of 34.519mm. Pipe strength would be decreased when applying high pressure steam through the pipe and ejecting through the holes under conditional environment. Due to high temperature in third segment pipe stress and deformation has been increased and getting broken after the critical stage.

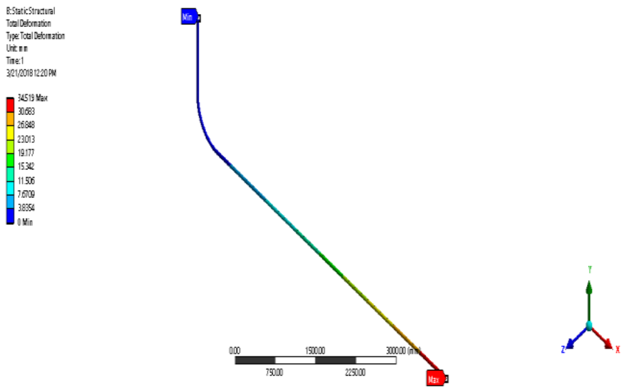

Fig.5 Deformation of steam pipe with holes

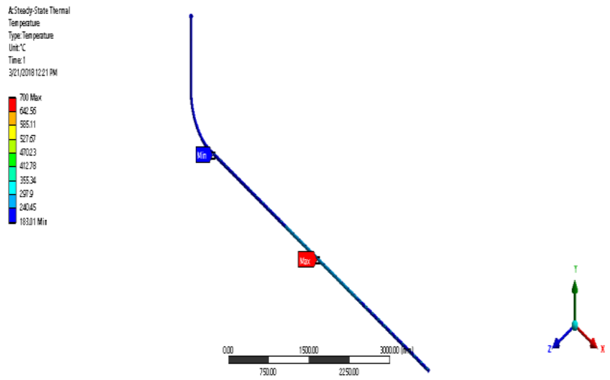

Fig.6 Temperature distribution of steam pipe having with hole

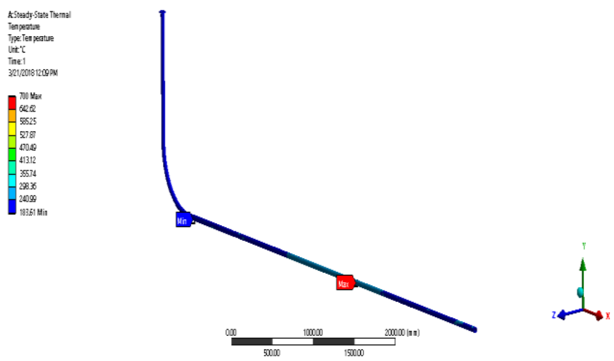

Fig.7 Temperature distribution of steam pipe without holes

The figure 6 & 7 shows the temperature distribution of a pipe with and without holes. The distribution of temperature is equal in both pipes under same conditions. Minimum value of temperature is 183.61^{O}C in pipe without having holes and 183.01 ^{O}C in pipe with holes and the maximum value of both pipes were 700 ^{O}C.

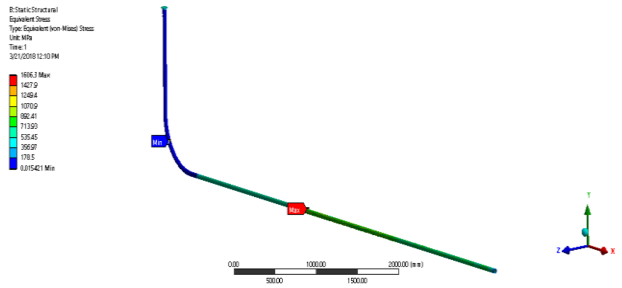

Fig.8 Equivalent stress of without holes steam pipe

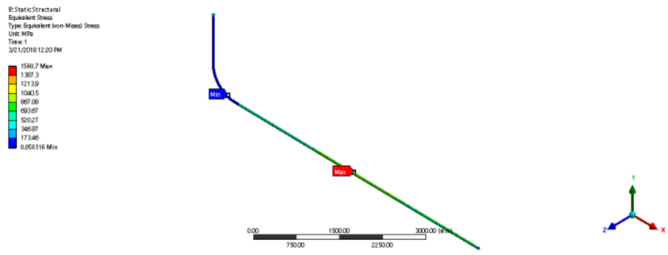

Fig.9 Equivalent stress of with holes steam pipe

Stress distributions of both pipes were shown in figure 8 & 9 which shows the stress distributions produced due to external and internal thermal loads. Most of the thermal loads occurred inside the pipe due to continuous input of high pressure steam. The pipe having without holes was produced maximum amount of stress and having with holes produced minimum amount of stress such as 1606.3 Mpa and 1560.7Mpa when compared with other. The supplied quantities of steam were uniformly released through the holes made the pipe produced minimum stress distribution.

8. CONCLUSION

Total deformation, Temperature distribution and equivalent stress distribution were analyzed to determine the life period and effect of steam pipe used in rotary kiln. Maximum and minimum deformation produced in pipes having with and without holes also the temperature distributions of pipes were same in both pipes. Equivalent stress distribution of a pipe having without holes was maximum whereas it was minimum in the pipe with holes.

The above three parameters were varied depends on the area of the pipe, material properties, input pressure of steam, surrounding temperature, internal and external condition of pipe. The pipe was getting damaged after a long periods the fracture was occurred in third segment of the pipe due to maximum temperature of segment and stress distribution.

Maximum holding time of a pipe during the process will allow getting fractures also which decreases the life of a pipe. Periodical cleaning and clinker removal of the pipe will increase the life of a pipe and the same time production of the respective product should not be affected.

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