Thermal Effects of Steam Pipe used in Activated Carbon Industry under Conditional Circumstances

Vijayan.S.N, Deepak.P, Duraimurugan.G.K

Abstract: High pressure and high temperature steam is used to activate the material contained in the activated zone of rotary kiln generally used in the cement manufacturing industry, activated carbon manufacturing industry, thermal processing industries. In this work, thermal stress behaviour of steam pipe with a zigzag hole is analyzed, which is used in the activated carbon industry where charcoal is used as a raw material. Steam is the most important factor for continuous activation process and must be uniformly distributed in the activated zone. Investigated the fracture produced in the heat affected region during the continuous process using ANSYS tool, also found the deformation, equivalent stress and temperature distribution for two types of pipes.

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

I. INTRODUCTION

Rotary kiln is a rotating equipment used for thermal treatment like calcinations, organic combustion, waste incineration and waste lime recovery. Rotary kilns are generally used in cement manufacturing industry, paper making industry and activated carbon manufacturing industry. The rotary kiln is a shell with internally insulated by refractory bricks, supported by support rollers 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. The kilns are rotating with respect to a horizontal axis with small inclination [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 into three working zones in first zone temperature would be approximately from $550^{O}C$, 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 as 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 generating fractures in the steam pipe due to the self weight, external and internal condition also affects the life of the pipe and quality of product [5]. Pipe line is always carrying high pressure and a high temperature steam, which is one of the most important reasons to the steam pipe receiving damage [6].

II. LITERATURE SURVEY

Initial defects of main steam pipe line in power plant were analyzed using probability and statistics method. Due to high temperature of steam, crack has been generated and increases continuously [6]. Various analyses were made in steam pipe used in different applications in that effect of Creep was analyzed for P22 material using software for elastic analysis [7]. Using non-linear finite element method Mechanical behavior and von misses stress distribution of high pressure pipe line with inner corrosion defect was analyzed [8]. High pressure pipe line with crack was analyzed using boundary element method to determine the fracture characteristics, and crack analysis of a thin tube was performed using finite element simulation method [9,10]. Mathematical model was build and developed for steam pipe system after the analysis of FEA for getting optimum weight and thermal effectiveness [11]. Thermal and static analysis has been done to calculate the stresses acting on the pipe by considering static and thermal load [12]. FEA tool is commonly used to calculate the thermal stresses, heat transfer rate and other mechanical and thermal properties and the temperature distribution of steam pipe was analyzed using theoretical method to validate the results with FEA [13, 14, and 19]. Thermal characteristics of a pipe are depending upon the liquid charge and the applied heat load [15]. Sustainability of a steam piping system was carried out using FEA and found that primary and secondary stresses were within the limit [16]. Dead weight stresses of piping system was analyzed by considering uniformly distributed weight with its insulation and considered the suitable supports [17]. High pressure steam distributed network was evaluated using analytical method. During evaluation all the parameters of the steam was considered such as type of flow, temperature and pressure [18]. Creep produced in the steam pipe is caused by internal pressure and stresses due to the effect of through-wall temperature gradient [20]. Failure analysis of steam pipe used in rotary kiln having straight holes steam distribution was analyzed to calculate the life and effect of pipe using FEA [21].

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III. PROBLEM DEFINITION

High pressure steam is the important factor for activating the material in the rotary kiln through chemical reactions. For supplying continuous and constant pressure steam, steam pipe is used in the rotary kiln. Activation efficiency is depends on the amount of steam supplied on the material in the activated zone. Holes are made on steam pipe in a zigzag way for constant interval and it is used for manufacturing special type of activated carbon. The pipe must be kept inside a rotary kiln for the whole period of process, due to this the pipe might be getting damaged or fractured around the holes of heat affected zone after a long period, also its reduced the life of pipe even the pipe has been taken out and cleaned periodically for every 12 hours. “Fig.1” shows a steam pipe used in rotary kiln for activation process.

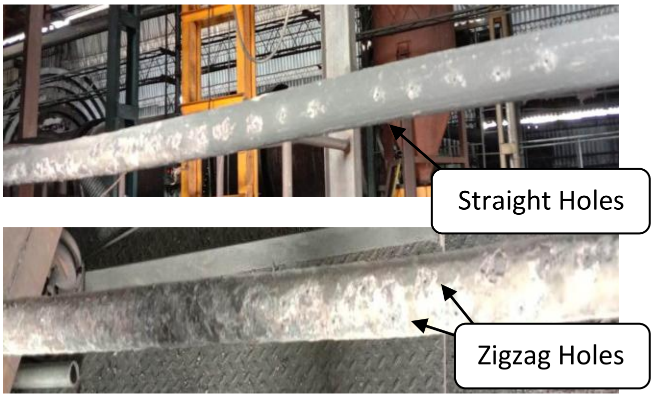

Fig.1 Steam Pipe used in Rotary Kiln.

IV. ATERIALS AND METHODS

Stainless steel pipe was used with 90,100, and 120 numbers of zigzag holes made on the pipe from the end. Steam boiler output is connected with the inlet of steam pipe with content pressure which is shown in “fig.2”. In the first stage the pipe was analyzed at static condition without supplying steam by considering self weight and second the pipe was analyzed with zigzag holes made on the pipe from closed end. The total deformation, temperature distribution and equivalent stresses were calculated for the pipes with and without zigzag holes.

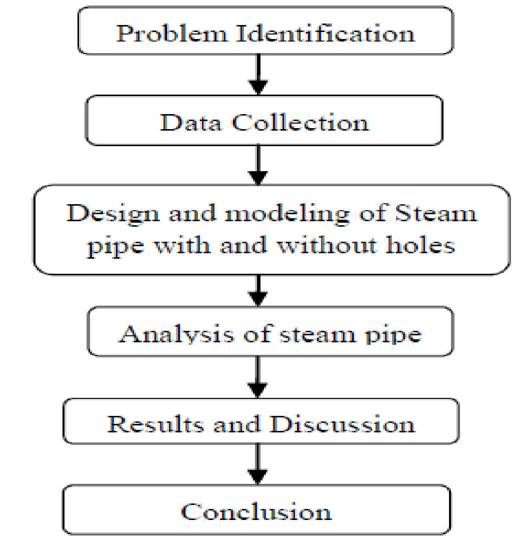

Fig.2 Methodology

V. DESIGN SPECIFICATIONS

Design calculation has been done to find out the appropriate pipe for the working condition and operating parameter. The Pipe has 5650 mm length with 46 mm external and 38 mm internal diameter, thickness of pipe was 4 mm and hole diameter is 2.7 mm which is made on the pipe from its end with an interval of 1 to 1.5 inches. The detailed sketch of the pipe is shown in “fig.3”.

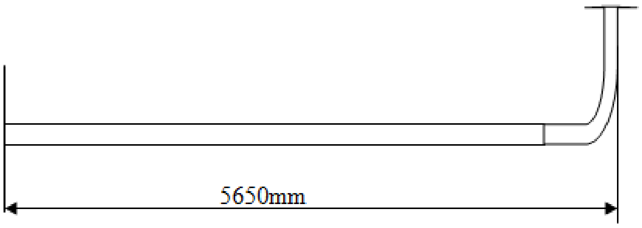

Fig.3 Steam Pipe

Table 1. Shows detailed dimensions of the pipe used in rotary kiln and taken for this analysis. The pipe dimensions will be varied depends upon the size and capacity of rotary kiln.

Table 1. Dimension of steam pipe

Sl.No	Description	Dimension in mm
1	Length	5650
2	Outer Diameter	46
3	Inner Diameter	38
4	Thickness	4
5	Hole diameter	2.7

A. Pipe thickness calculations

Selection of steam pipe size is very important for every application. Need to calculate the dimensions such as length and thickness of the pipe based on our working condition. Thickness of the pipe represents the strength and other mechanical properties during the working circumstance. Equation (1) is used to calculate the thickness of pipe.

$$t_m = \frac{PxD_o}{2x(SxEq+PxY)} + A \quad \text{......... (1)}$$

Where t_m is minimum thickness required, t is maximum acceptable pressure thickness, S is permissible stress at design temperature, internal pressure is denoted as p and outside diameter of pipe is denoted as Do. Allowance value is indicated as A, quality factor is denoted as Eq and assumed value of coefficient Y is considered as 0.4.

B. Working Pressure

Throughout the process steam pressure is maintained at two kinds of pressure level which includes maximum working pressure of the boiler and supplied pressure to the working area. While supplying steam pressure, loses happens due to the frictional resistance within the pipe and condensation of steam, for that reason allowance should be made when deciding upon the initial supply of pressure. Producing and supplying steam at maximum pressure gives three significant advantages that are increasing the storage capacity of boiler, required bore steam is small and minimum capital cost. When supplying high pressure steam, need to reduce the steam pressure to every point of use to maintain the maximum pressure.

C. Allowable Working Pressure

Maximum steam pressure is calculated using equation (2).

$$P = \frac{2(SxEq)xt}{(Do-2Yt)} \qquad \text{......... (2)}$$

Where

E_q=quality factor.

S=Allowable stress at design temperature, psi

t = specified wall thickness

Y = coefficient

Do = outside diameter

D. Load Calculations

In static analysis consider the loads such as static load, sustained load, wind load and thermal loads. For static analysis thermal load will be neglected due to the closed atmospheric condition. Assume that the pipe was in straight beam with uniformly distributed load when calculating static analysis and in normal operation sustained loads were generated due to the mechanical forces includes weight and pressure. Equation (3),(4)&(5) can be used for calculating steam weight and insulation weight of steam pipe.

$$\text{Pipe weight} = \frac{\pi}{4}\rho_{steel}\ x\ (Do^2 - Di^2)\ x\ \frac{g}{g_c} \qquad \text{............... (3)}$$

$$\text{Fluid weight} = \frac{\pi}{4} x \rho_{fluid}\ x\ Di^2\ x\ \frac{g}{g_c} \qquad \text{............... (4)}$$

$$\text{Insulation weight} = \text{insulation factor}\ x\ \rho_{insulation}\ x\ \frac{g}{g_c} \qquad \text{............... (5)}$$

Where external and internal diameter of pipe is denoted as D_0 and $D_{i,}$ insulation thickness is t, acceleration due to gravity and gravitational constant indicated as g and g_c. Density of steel, water and insulation is denotes as $\rho_{Steel,}$ ρ_{fluid} and $\rho_{insul.}$

In static condition stresses produced due to various loads such as sustained loading, occasional loading, wind load and dead load. A sustained load is the stresses produced by the effect of pressure and weight. Equation (6) is used to calculate the stresses produced due to sustained load.

$$S_L = \frac{PD_0}{4t} + \frac{0.75ixM_A}{Z} \qquad \text{......... (6)}$$

Where p is internal pressure (psi), Do is outer diameter of pipe (mm), t is nominal wall thickness (mm) and Z is section modulus of pipe (mm^3). Also, the stress generated due to occasional load that is earthquake.

Different loads are generated on the pipe during static and working condition and the loads are sustained load, wind load, dead load and thermal load. Sustained loads are caused by mechanical forces, weight and pressure loading. Insulation factor is calculated based on the insulation thickness. Wind load is a uniformly distributed load which acts along the entire length of the pipe which is exposed to atmosphere. For normal atmosphere, the wind dynamic pressure is calculated using the equation (7) and equation (8) is used to calculate wind dynamic load (lb/ft).

$$P = 0.00256xV^2x\ C_D \qquad \text{............7}$$

$$F = 0.000213xV^2x\ C_D x\ D \qquad \text{...........8}$$

Where dynamic pressure and basic wind speed is indicated as P and V, Drag co-efficient is denoted as $C_{D,}$ F is dynamic pressure load and D is diameter of the pipe.

E. Thermal Loads Calculations

Steam pipe is installed at the end portion of steam outlet from the boiler and which is perfectly located in the horizontal axis of rotary kiln with conditional atmosphere. Installation temperature must be minimum of 48^{O}C for cold insulated piping service and 5^{O}C for hot insulated piping service. During the process, steam pipe always carrying high pressure and a high temperature steam which generates a thermal load on the internal surface of pipe. External surface of steam pipe would be affected due to external thermal load produced by the operating temperature of kiln. Due to the continuous process stress, deformation and fracture will be produced on the surrounding of each and every hole that is made on the pipe. After a long period the pipe will receive crack in the point of high temperature affected zone. The quantity of the expansion is determined by using the following equation (9).

$$\text{Expansion (mm)} = \alpha \times L \times \Delta\ T \qquad \text{......... (9)}$$

Where ΔL is Length of pipe (m), T is difference between ambient and operating Temperature and α is Expansion coefficient. Thermal stresses of a pipe for three zones were calculated using the equation (10).

$$\sigma_t = \alpha \times L \times \Delta_T \qquad \text{......... (10)}$$

σ_t – Thermal Stress

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

Where L is pipe length and difference between operating and ambient temperature is ΔT.

VI. RESULT AND DISCUSSION

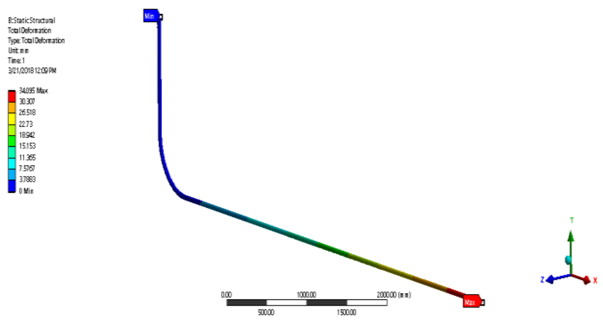

Fig.4 Deformation of steam pipe without hole

Total deformation of pipe without hole was analyzed by supplying high pressure steam at 12psi and shown in “fig. 4”. High level deformation has been produced in the third zone of pipe with 34.095mm. The important reason for the deformation of pipe was fixed only in one end and another end left free. Pipe strength has been decreased due to the thermal stress produced by the enclosed heat and continuous supply of high pressure steam which lead the pipe getting deformation. The deformation level has changed with respect to surrounding temperature and distance between pipe and heat generated zone. In general, during the process steam was not supplied using the pipe without hole.

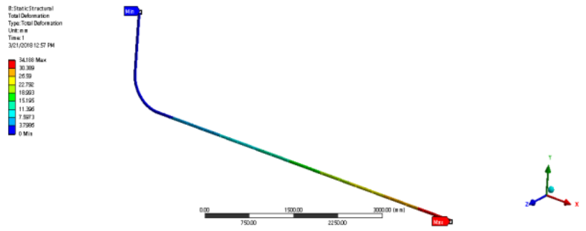

Fig.5 Deformation of steam pipe with zigzag holes

Zigzag hole would be used to maximize the distribution and direction of steam.When supplying high pressure steam and ejecting through holes under conditional environment gradually decrease the pipe strength and getting damaged at third zone due to high temperature. Deformation level of zigzag hole pipe was maximum when compared with pipe without holes. Highest deformation occurred in third zone of the pipe was 34.188 mm, it is shown in “fig.5”.

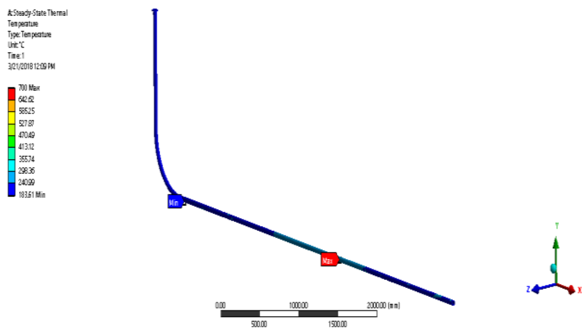

Fig.6 Distribution of temperature in steam pipe (without holes)

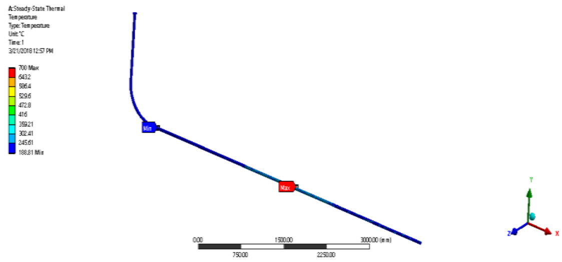

Fig.7 Distribution of temperature in steam pipe (with zigzag hole)

Temperature distribution of steam pipe with and without zigzag hole were analyzed and shown in “fig.6” and “fig.7”. The enhanced temperature in pipe with zigzag hole is due to larger steam distribution area and enclosed condition of pipe in the third zone, the value of temperature obtained in the pipe without zigzag hole is 183.61^{O}C and with zigzag hole is 188.81^{O}C.Maximum temperature of both pipes is 700^{O}C, although the temperature distributionrange from minimum to maximum value is different for both pipes.

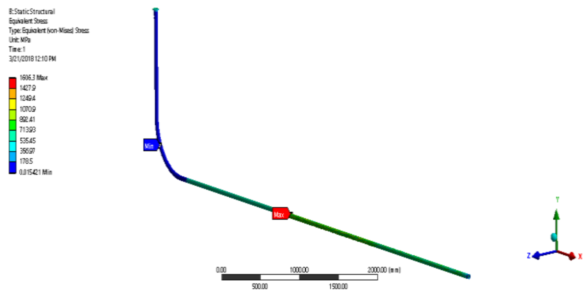

Fig.8 Equivalent stress of steam pipe without holes

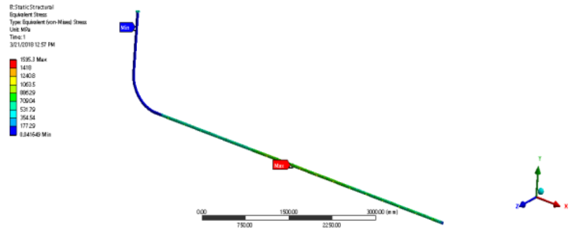

Fig.9 Equivalent stress of pipe with zigzag holes

Stress distributions of both pipes were shown in “fig. 8”and“fig.9”which indicates 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 without holes produced maximum amount of stress and pipe with holes produced minimum amount of stress such as 1606.3Mpa and 1595.3Mpa.

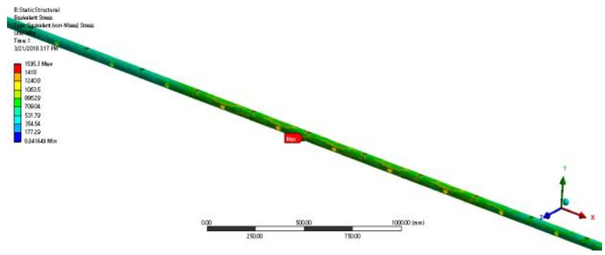

Fig. 10 enlarged view of zigzag pipe

The supplied quantities of steam were uniformly released from the pipe with holes which leads to minimum stress distribution. The enlarged view of zigzag pipe was shown in “fig.10”.

Table. 2 Analysis Results

	Total Deformation (mm)	Temperature Distribution (Degree Celsius)	Equivalent Stress (Mpa)
without hole	34.095	700	1606.3
zigzag hole	34.188	700	1595.3

Analysis results are tabulated in Table. 2 and “fig.11” illustrates the graphical output of results obtained from the analysis.

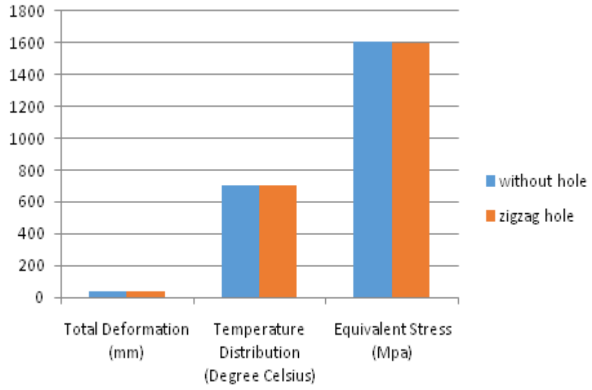

Fig. 11 Graphical Representation of Analysis Results

VII. CONCLUSION

Total deformation, Temperature distribution and equivalent stress distribution were analyzed to determine the life period and the effect of steam pipe used in a rotary kiln. In practice, pipe without a hole is not used. In this work without hole pipe was used only for validating the performance results with pipe having holes.

The higher deformation level has been occurred in a pipe with zigzag hole because of the internal and external thermal stress. When compare to external thermal stress internal stress could be negligible. The deformation level is gradually increased until getting fracture, if the pipe is kept inside the kiln for a long period.

Maximum temperature of both the pipes were almost same, however the distribution of temperature from minimum to maximum were varied when compare with other. Pipe with zigzag hole has produced minimum amount of stress distribution because of constant and large area used for distribution of steam.

Life of the pipe can be varied depends on the design of pipe, material properties, input pressure of steam, surrounding temperature, internal and external condition of pipe, process parameters. The pipe was getting damaged after it reaches the fracture in a third segment due to the maximum temperature and stress distribution.

Maximum holding time of a pipe during the process will generate fractures and 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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