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Modelling and Flexibility Analysis of Hydro Cracker Unit

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Abstract— ***Hydro cracking is an extremely versatile catalytic process in which feed stock ranging from Naphtha to Vacuum Residue can be processed in presence of Hydrogen and catalyst to produce almost any desired products lighter than the feed. Primary function of Hydrocracker unit (HCU) is to maximize middle distillate production. First stage feed heater is a twin cell cabin heater with horizontal radiant tubes supported through 3 nos ladder type coil supports. Radiant Coil vibration was observed in tubes some remedial measures pertaining to mechanical aspects were studied and implemented. However, a need of comprehensive study to identify and minimize the coil vibration problem was felt to ensure reliable operation of the heater. In this work, Flexibility analysis of Heater Radiant Coil by modeling applied end conditions and various temperature cases was performed to verify the mechanical design and to understand the probable reasons of coil lifting. Fatigue analysis of the vibrating coil with maximum stress amplitude obtained by Flexibility analysis was performed. The maximum possible slug forces was calculated and dynamic analysis of reactor inlet piping along with heater coils was carried out to check whether slug, if any, has any impact. Maximum tube metal temperature for a definite span of operation was estimated. Purpose of this work is carried to identify the probable reasons of heater radiation tube lifting and vibration and to suggest remedial measures to continue safe operation of the heater. Heater tubes have a life of definite span which is directly related to the operating tube metal temperature. Due to furnace running on high tube metal temperature, rupture design study was also carried out for remaining life assessment of the tube. Based on the flexibility analysis of radiant tubes and maximum tube metal temperature calculation, heater operation could be sustained safely without unit interruption due to heater***

Index Terms—Fired Heater, *Hydro Cracking, Tube Lifting, CAESAR Analysis*

I. INTRODUCTION

Oil and gas industry has been using various design standards, codes and specifications through these years of success. Region to region, these may have differences due to its regulations and requirements. The background for this work is the desire to obtain better understanding about design part of the ASME B31.3 process piping code and its application in the furnace tubes and transfer piping. . The main challenge of this piping code is to understand how the stresses in a pipe are treated and handled. This code has its own way of treating and handling these stresses. As this code, piping systems can be imposed of various loadings. Due to cyclic loadings, piping systems can be failed even before stresses reaching the yield stresses of the pipe and this is called fatigue failure. Especially offshore piping systems which are subjected to high cyclic wave loadings can be critical on the fatigue failures. The ASME B31.3 piping code doesn't necessarily address these failures thoroughly. So there is a need to use other piping codes for the better understanding of these failures

A. Fired Heater

A fired heater is a direct fired heat exchanger that uses the hot gases of combustion to raise the temperature of a feed owing through coils of tubes aligned throughout the heater within an internally insulated enclosure. Depending on the use, these are also called furnaces or process heaters. Some heaters simply deliver the feed at a predetermined temperature to the next stage of the reaction process; others perform reactions on the feed while it travels through the tubes.

B. Hydro Cracker

In Hydrocracker, the VGO feed is subjected to cracking in two stage reactors over catalyst beds in presence of Hydrogen at pressure of 170 kg/cm^2 and temperature ranging from 365 to 441^{o}C. The cracked products are separated in fractionator. Light ends are recovered in debutanizer column. The process removes almost all sulfur and Nitrogen from feed by converting them into H2S and Ammonia respectively. Thus the products obtained are free of sulfur and nitrogen compounds and saturated. Therefore, except for mild caustic wash for LPG, post treatment is not required for other products.

C. Tube Lifting

Based on engineering and operational experience and material behaviour, following reason were identified as probable reason that may lead to tube lifting and vibration-

1) Thermal expansion of the ladder.
2) Higher Furnace load due to unit running at higher throughput.
3) Restriction of tube at inlet/outlet sleeve and/or cross guide.
4) Restriction of tube at supports.
5) Piping anchored and piping movement imposed on to the heater coil in operating condition.

D. CAESAR Analysis

CAESAR II incorporates a robust static solver, employing both the Choleski methods as appropriate. The static solvers are designed to iterate to a converged solution, modifying the global stiffness matrix as the status of non- linear restraints changes.

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Once the static displacement solution is available, element forces and moments are computed, followed by the element stress computation according to any of the 21 built-in piping codes.

II. OBJECTIVE

Study and analysis of furnace coils has been carried out with objective of-

1) Determination and comments for further serviceability of heater based on analysis of the loads and moments imposed on the heater tubes or attached transfer piping by tube lifting.
2) Analysis of the stresses in the tube in both the cold and hot conditions to ensure same is below the allowable limits
3) To study and understand the probable reason of coil lifting and coil vibration.
4) Fatigue failure analysis for the vibrating tubes.
5) Verification of the design conditions and analyzing the site irregularities observation using Software.
6) Due to increased furnace load and End of Run (EOR) condition of the unit, tube metal temperatures are crossing design limit. Hence study to be done for maximum allowable tube metal temperature for safe operation of furnace.
7) Minimizing the lifting and vibration problem and improvement of reliability of furnace operation.

III. METHODOLOGY

To satisfy the piping code requirements and to do the analysis with reliable, practical and economical way, there is only one way and that is to get help from dedicated and commonly used pipe stress software with the piping code check module or the beam elementary theory. For extensive stress analysis in this work there has been used software called CAESAR II 5.10 version.

The problem of tube lifting and tube vibration as discussed in this project is not a common problem. We have applied Cisco's eight-step troubleshooting method for arriving at the probable cause. The most important part of troubleshooting any problem is to divide the tasks of problem resolution into a systematic process of elimination. Cisco has broken this process into eight steps:

1) Define the problem.
2) Gather detailed information.
3) Consider probable cause for the failure.
4) Devise a plan to solve the problem.
5) Implement the plan.
6) Observe the results of the implementation.
7) Repeat the process if the plan does not resolve the problem.
8) Document the changes made to solve the problem.

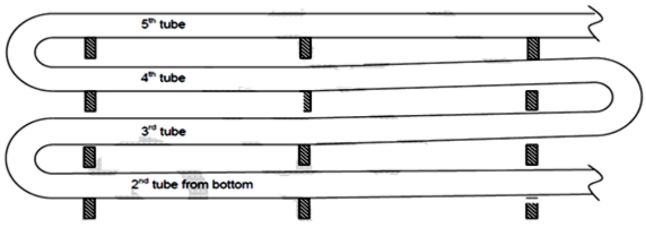

Fig. 1: Furnace Tube Layout

A. Flexibility Analysis

The stresses due to thermal expansion loads in a piping system can be calculated with following standard equations

$$S_E = \sqrt{(S_b)^2 + 4(S_t)^2}$$

Where S_E = computed displacement stress range
S_b = resultant bending stress
S_t = torsion stress
The torsion stress can be calculated as follows:

$$S_t = \frac{M_t}{2Z}$$

Where
M_t = torsion moment
Z = sectional modulus of pipe/matching nominal pipe
For full size outlet branch connections, the resultant bending stress S_b is calculated as follows

$$S_b = \sqrt{\frac{(i_i M_i)^2 + (i_o M_o)^2}{Z}}$$

Where Mi = in plane bending moment
M_o = out plane bending moment
i_i = in plane stress intensification factor
i_o = out plane stress intensification factor

B. Stress Analysis

Some piping systems can be more critical and more difficult to design than others because of the temperature variations, vibrations, fatigue. It is important to do stress analysis for the piping systems. But most of the piping systems can be visually checked and see that the system is accepted. For others it is necessary to do a detailed stress analysis. It includes the analysis of various modes of failure such as ductile and brittle rupture, high and low cycle fatigue and creep rupture etc.

Mostly for the design purpose and the stress analysis purpose, it is only considered the loading that are applied in the service life of the piping system. Considered loading are discussed as in the following.

1) Dead weight load is the sum of weights from all the pipe and piping components such as flanges, bends, tees, bolts, valves, insulation, inside content and etc.
2) Internal pressure load is the static end cap pressure load that act on the cross sectional area of the pipe caused by the internal pressure.
3) Sustained loads are resulting to the primary stresses and those loads are not set limiting. Sum of the dead weight loads, axial loads caused by internal pressure and other axial loads that are not caused by the thermal expansion can be expressed as sustained loads. As these loads are acting, the longitudinal stresses will be resulted and all those stresses must not exceed the basic allowable stresses of the materials. The pressure is normally considered as sustained load but there can be pressure cycles and pressure surges which are not considered as sustained loads. When there are pressure cycles, it has to take into consideration in fatigue analysis. For the stress analysis and the design purposes, it is required to use the design pressure not the operating pressure.

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4) Occasional loads Wind, earth quake, waves, snow and ice accumulation, dynamic loads such as pressure relief loads, fluid hammer, slug and etc are some examples of occasional loads. In the North Sea installations design process, it may not a requirement to consider the earth quakes as a design load and therefore it is not discussed further in this work

IV. SOFTWARE ANALYSIS

A. Modeling of Radiant Coil

The radiant coil was analyzed by CAESER software to analyze the peculiar behavior of coils and related vibration. The radiant coil (inlet to outlet) was modeled as per drawing and data-sheet. CAESAR Screen shifts for furnace coil assembly and coil assembly with transfer piping has been attached as screen-shots below. Modeling of the furnace radiant coil as per original equipment drawing done for two cases:

a) Furnace coil and

b) Furnace coil along with transfer piping

Further, for the purpose of simplification and calculation

1) It is assumed that operating pressure is uniform and is equal to rupture Design Pressure of 198 Kg = cm^2 as specified in API datasheet. Hence, equal stresses have been used for calculations.

2) A uniform temperature has been considered during a Temperature-Time-Span.

3) Also, it is assumed Outer Diameter remains constant.

4) Zero and One mm corrosion is considered for two separate calculations.

Table I: Ladder Displacement Due to Thermal Expansion

Tube from Top	Ladder Displacement Due to Thermal Expansion
1st	-9 mm
2nd	-13.98 mm
3rd	-18.97 mm
4th	-23.95 mm
5th	-28.94 mm
6th	-33.92 mm
7th	-38.9 mm
8th	-43.89 mm
9th	-48.87 mm
10th	-53.86 mm

B. Flexibility Analysis

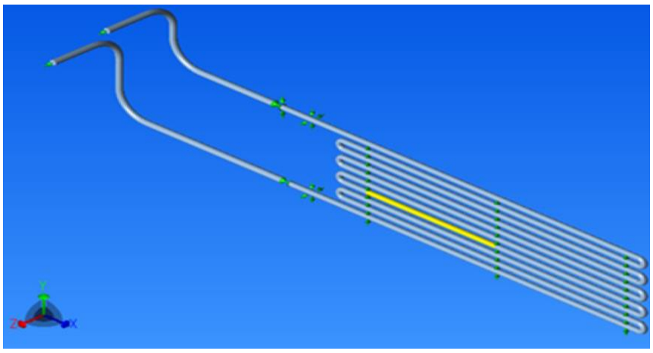

Fig.2: Modeling of Furnace Coil Assembly

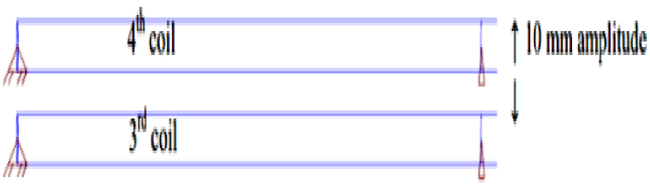

Fig.3: Section of Coil Modeled in CEASAR II

Flexibility analysis of the radiant coil with Caesar II software to analyse the behavior of coil at various operating conditions, mechanical design conditions, peculiar behavior of coils, stress values at various nodes:

1) Failure assessment of coil in as lifted condition.

2) Design conditions were evaluated by Caesar software.

3) Trial Cases were also analyzed taking CAESAR runs with piping anchored and piping movement imposed on to the heater coil in operating condition.

V. RESULT

A. Design Check

The configuration defined as per design condition is as shown above: Vertical supports at Ladder location with C node causing these supports to move by following distance in operating case (based on thermal expansion of ladder supports) Result : Cesar run was obtained as per design conditions (Refer Annexure R1). All

B. Flexibility Analysis for Lifted Condition

Flexibility analysis of the furnace coil was carried out for lifted condition as observed at site. Tube lifting was imposed at nodes corresponding to south side ladder crossbar and north side ladder cross bars and Caesar run was obtained. Result: Caesar run confirms for present lifting scenario exerted stress is well below the allowable limits. Maximum code stress was observed at node 120. Code stress value (code stress/allowable stress) at node 120 was 69.4 for sustained load case. Detailed output of the Caesar II software has been furnished in Annexure I

C. Ruptures Analysis of Vibrating Tubes

(Tube no. 3 and 4) B.1 Fatigue analysis was carried out in CAESAR II piping stress analysis software to determine the fatigue life of the coil due to vibration. By infrared vibration analyzer maximum amplitude of vibration was about 10 mm and the frequency about 2 Hz. B.2 the 3rd and 4th coils of the furnace were modeled in CAESAR II. Only the section south of the middle ladder is modeled. Anchor boundary conditions are assumed at the middle ladder as this boundary condition is expected to be more conservative, giving higher stresses and lower fatigue life. A displacement of 10 mm is imposed in the upward direction at the bend and in another case 10 mm displacement in the downward direction is imposed. A fatigue case is constructed between these two cases.

VI. CONCLUSION

From piping flexibility analysis by Caesar II study and remaining life calculation following conclusions may be drawn-

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1. Thermal expansion of ladder is not the reason for lifting of tube no. 3 and 4.
2. Caesar analysis confirms that the above condition does not cause any coil failure in cold/operating case i.e. at no point induced stress is more than allowable stress.
3. The coil was found to be seating at all the supports in bottom-most tube in operating condition in normal design conditions.
4. Piping movements imposed on heater coil results in lifting of tubes at south side ladder. However as per drawing, cross-guide is provided to allow 5 mm coil movement away from heater and do not allow coil movement towards heater.
5. CAESAR run confirms that Transfer piping (pipe from furnace to reactor) obstruction at the piping support location and coil inward movement will contribute towards tube lifting.
6. CAESAR run also confirms that Weld beads for old tubes restricting thermal expansion of tubes as the same is at approximately 60mm from middle-Ladder flanges whereas the expansion of tube at middle ladder is more than 70mm.
7. Piping movements restricted at the sleeve, cross guide and outlet piping at supports location will lead to coil lifting from supports at south side ladder. However, lifting phenomenon i.e. lifting of tube 2, 3 and 4 without lifting of tube no. 1 were not elaborated by the Caesar software.
8. Tube remaining life assessment suggest that tube possess good life and can be operated safely upto 590 deg C with adequate assessment of supporting system.
9. Technical literature study suggests flow induced vibration due to two phase flow inside the tube to be the probable reason for vibration of the furnace coil.
10. Flexibility and rupture analysis suggest that there is no limitation in furnace mechanical design and is cleared for operation. Based on this work and Caesar preliminary analysis, restriction to furnace outlet piping at cross guides, supports etc. were rectified which led to reduction in tube lifting and vibration. Stresses were analysed for worst condition and based on the same furnace operation was continued successfully.

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