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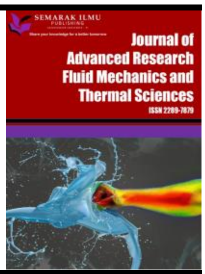

Failure of 24 Inches Blowdown Tower Inlet Nozzle Due to Cyclic Surge Forces

Mohd Zainuddin Awang Ahmad[1], Suzei Mat Nurudin[2,*], Arman Anuar[1], Mohd Shukri Yob[3], Muhammad Anas Omar[4]

[1] Petronas Technical Services Sdn Bhd, Persiaran Penapisan, 76300 Sungai Udang, Melaka, Malaysia
[2] Faculty of Administrative Science and Policy Studies, Universiti Teknologi Mara, Seremban 3, Negeri Sembilan, Malaysia
[3] Advanced Manufacturing Center (AMC), Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[4] Universiti Teknologi Petronas, Tronoh, Perak, Malaysia

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ABSTRACT

Blowdown tower is one of the equipment in closed blowdown system (CBS) in Delay Coker unit in petroleum refinery. The primary intended function of the CBS is to flush out hydrocarbon vapours from coke drum using high pressure steam into blowdown tower. The system is operating in batches and cycles, due to constant operation at various temperature, pressure, and conditions, components are susceptible to various of failures including thermal fatigue, crack, corrosion, and others. Crack incident was observed on the welding of blowdown tower nozzle that connected to closed blowdown system (CBS) piping after 11 years of operation. This paper aims to study the structural integrity and risk level of the CBS system in relation to liquid level in receiving tower (blowdown tower). Dynamic piping stress analysis and Finite Element Analysis (FEA) was conducted on this line and blowdown tower nozzle to evaluate the overall material behaviour and assessed the risk of failure. The acceptance criteria of the analysis were set to be based on ASME VIII-Division 2 part 5.2.2 (Elastic Stress Analysis Method) and ASME II-part D. Findings from FEA shows that the failure occurred on the blowdown tower nozzle was due to surge pressure impact from high pressure steam flow to obstructed high liquid elevation at the inlet nozzle. The high surge pressure that happened near the nozzle has caused the stress to exceed allowable level thus initiated the crack in cyclic/ batch service. It is recommended that petroleum refinery to continuously maintain the blowdown tower level below nozzle to prevent similar phenomenon to happen in future.

1. Introduction

Several processes are required in a petroleum plant in order to transform crude oil into useful products such as naphtha, gasoline, fuel, and gas. A refinery plant is separated into multiple units due to the difference in processing conditions.

* *Corresponding author.*
E-mail address: suzei509@uitm.edu.my

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Each unit is made up of fundamental components such as pressure vessel, heat exchanger, tank, boiler and many more, which all of them are link together by a pipe or a line. The Delayed Coker Unit (DCU) for example, is a semi batch process for converting the densest and least attractive crude oil into a viable product.

The coke drums in this unit are subjected to high heat cycle due to the nature of the process. These drums are typically exposed to high temperatures up to 480 °C for extended periods of time. After that, a rapid steam quenching followed by a long water quench was used to cool the remaining material to a safe operating temperature. This method, on the other hand, mechanically stresses the drum shell. These drums run at a variety of pressures (from 0 to 345 MPa) over the course of a whole operation cycle [1].

Although the operating streams pressure and temperature are known and controlled, the actual stress on the drum pressure envelope is unknown, particularly during the water quench stage, when large volumetric flow rates are influenced by the distribution, density, porosity, and internal channeling within the residual coke mass. This cyclic repetitive strain poses a serious threat to the body and components of the drum [2]. During steam out, back warming, and water quenching in the Closed Blowdown System (CBS), temperatures at the inflow header to blowdown tower vary (between 120 and 340℃). This procedure was carried out for up to 2 hours, resulting in cyclic temperatures.

Welding joints which are susceptible to cyclic stress and strain are the most likely to fail among other sections. This is because of welding process has altered mechanical and physical properties of a metal in order to weld them together. Many piping failures have been documented because of cyclic temperature and pressure [3-8]. The rate of crack propagation is substantially faster when the temperature is raised, according to these studies. They also discovered that one component contributing to the increased crack growth rate at higher temperatures is the higher stress intensity factor that induced by high temperature variations [3,9]. This was considered since the crack growth rate increased as the stress intensity increased, according to the Paris Law [3,4,10-12].

A pressure surge or liquid hammering phenomenon in a piping system could occur if the rate force to stop or change direction suddenly [13]. It is quoted as the most damaging instability in terms of aerodynamics and mechanical structure [14]. Shutting down a pumping station or pumping unit, unstable controls, oscillation in tank levels, the quick closure of a valve, or any other sudden stoppage of the flowing fluid could cause pressure surges [15]. All fluid in piping systems is susceptible to pressure surges which can lead to piping fatigue and collapse. Surge can cause catastrophic failure of the pipeline system and equipment, as well as fatigue failure of pipeline supports, instrumentation, equipment, and chemicals [15]. Surge also generate extreme pressure oscillations, changing steady state operating conditions and putting the pipeline system at risk of structural damage [16]. In addition, surges of varying magnitudes exert varied forces on mechanical and aerodynamics structures [14].

As previously stated, stress and failures can be predicted and avoided with good pipe flow design and analysis. Hence, the purpose of this paper is to investigate the CBS system structural integrity and danger level in connection to the liquid level in the receiving tower (blowdown tower). The study was conducted using manual calculation and software simulation using Ceasar II and ABAQUS 6.13. The simulation result then verified against actual damage condition at site. The outcome of this study was expected to provide a clear and concise analysis on surge phenomenon that occurred in the petroleum piping for future planning on piping system.

2. Problem Statement

2.1 Problem to be Countered

Blowdown tower inlet nozzle that connected to 24 inches CBS piping was found cracked after 11 years in operation. The incident has caused the unit to be shut down for repair due to loss of containment and subsequently caused the refinery to suffer loss of production.

The nozzle was constructed from carbon steel material of ASTM A 105 and was designed to ASME VIII div 1 code. The crack was a through wall cracked that led to loss of containment of the product as shown in Figure 1. It was recorded that in 2011, more than 59% coke drum blowdown were executed during liquid level above 99% of the blowdown tower level (Figure 2). The liquid level was higher than nozzle elevation during the blowdown activities executed.

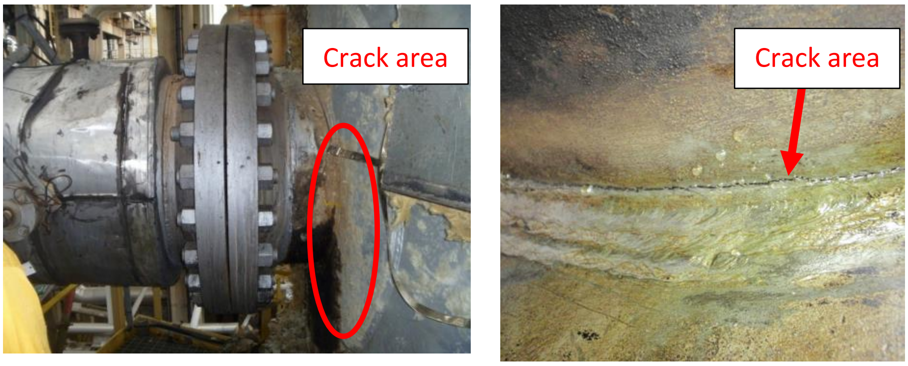

Fig. 1. Quench tower inlet nozzle N5 crack (in circle) at 180 deg location

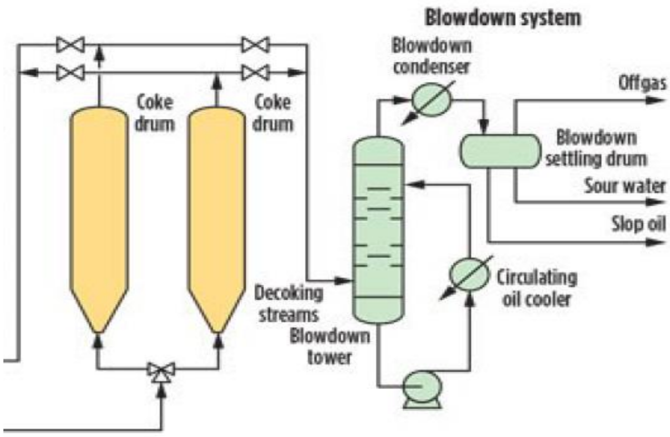

Fig. 2. Coke Drum blowdown system

2.2 Analysis on Crack

Root Cause Failure Analysis (RCFA) was conducted to investigate root cause of the incident. It was identified that Piping stress analysis using Ceasar II and Finite Element analysis using ABAQUS 6.13 software required to be performed in order to simulate the incident. The acceptance criteria of the analysis were referred to the ASME VIII Division 2-Part 5.2.2 (Elastic Stress Analysis Method) and ASME-Part D.

In order to conduct piping stress analysis, surge force calculation was conducted using Joukowsky direct pressure surge method. In this analysis, the surge pressure was assumed to be half of calculated surge load since the impact of high level of liquid level in quench tower could be lesser than impact of solid metal e.g., valve.

Using Joukowsky direct pressure surge method [13,17]

Pressure rises above normal operating;

$$\triangle P = \rho a \Delta v$$

$$\triangle P = \frac{av}{100} - P_{OPE}, and$$

$$\triangle h = \frac{av}{g} + static\ head$$

$$Surge\ Force, F = \triangle P.A$$

Dynamic stress analysis using time history was conducted to determine impact forces of the obstructed high pressure steam flow at the nozzle. The analysis was conducted with the scenario of surge phenomenon to happen at that condition. Later, finite element analysis of the nozzle section conducted to determine stress concentration contour at the weldment due to surge load impact.

Thermal fatigue screening also conducted according to ASME VIII Div 2, Fig 5-110.1 in order to consider probability of the thermal fatigue failure. The calculation below used to calculate allowable cycles, N.

$$\frac{N}{N_i} = \left[\frac{N_j}{N_i}\right]^{\frac{log\ (S_i/S)}{log\ (S_i/S_j)}}$$

Finally, finite element analysis using ABAQUS 6.13 of the nozzle section conducted to determine stress concentration contour at the weldment due to surge load impact. The model was assigned with 3D stress element with hexahedron(brick) shape and with optimal mesh size of 12. The model was assigned with fix boundary condition that applied along perimeter along of the modelled shell, the reference point created at the center of nozzle opening in order to obtain global force. The model accuracy was tested with initial 100 barg which the same value of wall thickness calculation for ASME VIII Div1 which resulted of 7% accuracy.

3. Results

The RCFA found that the cracks were due to phenomenon of surge. Despite the absence of a shutdown valve upstream of the 24 inches nozzle (N5) (Figure 3), the projected overflow liquid level up to nozzle N5 combined with apparent piping vibration at the point of interest can be justified as the closing valve. Although the momentum of the liquid smashing into the overflow liquid is not the same as the flow hitting the shutdown valve, it can cause a pressure rise that can cause the nozzle to burst if there is no axial stop in place to handle such pressure. Detailed inspections were conducted using time history analysis in dynamic spectrum mode founds that in various sites along the piping system, stresses exceed the ASME B31.3 permissible levels and the calculated forces and moments for the N5 nozzle are quite high. It also finds that the N5 nozzle is additionally strained in violation of WRC 107.

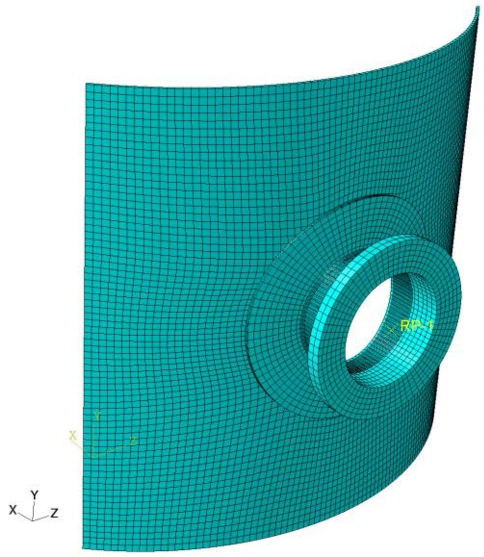

Fig. 3. FE mesh model for nozzle 24 inches of Blowdown Tower

Reaction from time history features in Caesar II simulations were then implemented on the FEA model as shown in Figure 4 while the stress concentration in FEA model of nozzle section area is shown in Figure 5. It shown that high stress concentration at the location shown in Figure 4 permeates through the wall of nozzle. Thus, area that are exposed to surge phenomenon will have high stress intensification.

FEA results in Figure 4 shows that area on the nozzle that are not exposed to the surge, give lower stress intensification. Thus, highest stress intensification was obtained on the area that are very exposed to the surge phenomenon. The highest stress was recorded at 155.75 MPa which is the cause of failure due to the value exceeds the allowable stress of 118 MPa (at 220 degC). The nozzle neck is very prone to fatigue failure due to the high number of cyclical stresses and the number of cycles exceeding 4500, as determined by API 579. This finding was also supported by earlier research where when the maximum value exceeded the maximum pressure that could be tolerated, damage consequences such as resonance phenomena may result in a pipeline system fatigue process [16].

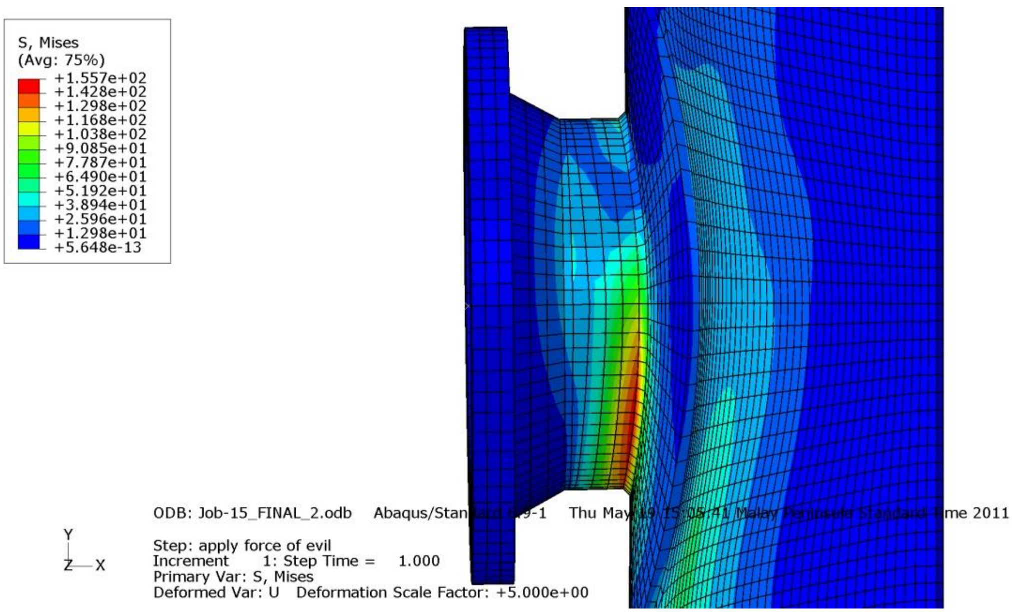

Fig. 4. Stress concentration in FEA model of nozzle section area (red and yellow area)

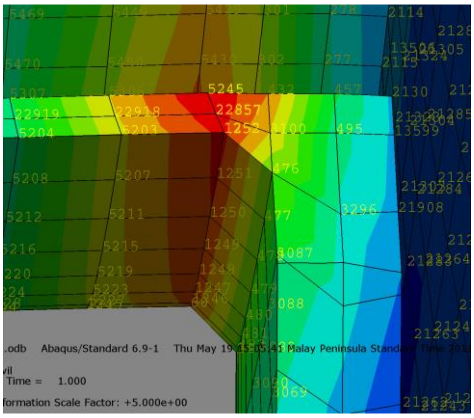

Fig. 5. Location of the node that gives high value of stress intensification (red and yellow area)

4. Conclusions

This study shows that the phenomenon of surge brings high stress concentration as happened in this nozzle case. Based on this study, the fatigue failure due to surge phenomenon shall be taken into consideration during the designing phase of the system. The study has shown the force pressure of 8.63 barg, and surge force of maximum of 118.184 kN. Thus has lead to maximum stress value recorded of 155.75 MPa at the nozzle which exceeded allowable value from ASME II Part D. This is because the amount of stress intensification at the area that are exposed to the surge phenomenon will be the weakest area that will become a factor for fatigue failure in the system. It is therefore recommended that operating team to ensure liquid level inside the blowdown tower to be given priority in monitoring in order to avoid potential of surge phenomenon could re-occur in this CBS system.

The entire piping system needs to be evaluated for fatigue using either the SN-Curve from ASME VIII Div. 2 Appendix 5 or the fatigue approach described in ASME B31.3. For future studies, the simulation could be done in lab with extra scenarios including additional variables and to verify assumption in this study when assuming high liquid level in the blowdown tower as half of surge load impact.

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