

PAPER • OPEN ACCESS

Fatigue life estimation on coke drum due to cycle optimization

To cite this article: Andrey Stephan Siahaan *et al* 2018 *J. Phys.: Conf. Ser.* **1005** 012002

View the [article online](#) for updates and enhancements.

You may also like

- [Kinetics and percolation: coke in heterogeneous catalysts](#)
Vladimir P Zhdanov
- [Temperature Field Acquisition And Data Analysis Of Coke Oven](#)
R T Zhao, W Q Liu, J S Wei et al.
- [Interfacial reactions between DBD and porous catalyst in dry methane reforming](#)
Seigo Kameshima, Ryo Mizukami, Takumi Yamazaki et al.



The Electrochemical Society
Advancing solid state & electrochemical science & technology

243rd Meeting with SOFC-XVIII

Boston, MA • May 28 – June 2, 2023

Accelerate scientific discovery!

Learn More & Register



Fatigue life estimation on coke drum due to cycle optimization

Andrey Stephan Siahaan¹, Himsar Ambarita^{2,*}, Hideki Kawai¹, and Masashi Daimaruya¹

¹Department of Mechanical Systems of Engineering, Muroran Institute of Technology
27-1 Mizumoto-cho, Muroran 050-8585, Japan

²Sustainable Energy Research Centre, Faculty of Engineering, University of Sumatera Utara, Jl. Almamater Kampus USU Medan 20155, Indonesia

E-mail: himsar@usu.ac.id

Abstract. In the last decade, due to the increasing demand of petroleum product, the necessity for converting the heavy oil are increasing. Thus, demand for installing coke drum in whole world will be increase. The coke drum undergoes the cyclic high temperature and suddenly cooling but in fact is not designed to withstand that kind of cycle, thus the operational life of coke drum is much shorter in comparison to other equipment in oil refinery. Various factors determine in order to improve reliability and minimize the down time, and it is found that the cycle optimization due to cycle, temperature, and pressure have an important role. From this research it is found that the fatigue life of the short cycle is decrease by a half compare to the normal cycle. It also found that in the preheating stage, the stress peak is far exceed the yield strength of coke drum material and fall into plastic deformation. This is happened because of the temperature leap in the preheating stage that cause thermal shock in the upper part of the skirt of the coke drum.

Keywords: Coke Drum, Fatigue Life Estimation, Preheating Stage, Cutting Stage

1. Introduction

Coke drum are vessels critical to the operation and profitability of today's oil refinery and tar sand facilities. These vessel operate in batch cycle at relatively high temperature; approximate 430°C to 500°C, and about once a day, they are filled with vapor and hot oil and finally quenched with water. Coke drum designed according to ASME Section VIII division II pressure vessel with little or no account for the cyclic operation fatigue service in which they operate [1].

In general temperature history can be divide into four stages. First is preheating stage from 0 to 440 minutes, second is filling stage from 440 to 2000 minutes, third is cooling stage from 2000 to 2400 minutes, and the rest is cutting stage. Typical operational temperatures for one cycle are shown in fig. 1. In the figure, temperature of point T1 and T8 are only shown. As a note, temperature of the shell portion of the coke drum are represented by points T5 and T8.

In the preheating stage to avoid harmful thermal shock, the coke drum is preheated. Thus, all temperature increase as the time increasing. Since the coke drum is heated from inside, increase of shell portion is bigger than the skirt [2]. As the result, temperatures of points T1 to T4 are relatively bigger than T5 to T8. In other words, the shell is hotter than the skirt. However, or a while, at the beginning of



preheating stage, normally the lower part of the skirt is hotter than the upper one. This is because of remaining heat from previous cycle.

After the preheating stage is finish, in the filling stage, the hot feed material is injected into coke drum. Since the temperature of coke drum is lower than the hot feed, at the beginning of filling stage, coke drum temperatures increase rapidly. After that temperature become flats or quite constants on filling stage. As a note, heat is transferred from coke drum to surrounding through the wall and through the skirt to the base. Since so, the shell of the coke drum is hotter than the skirt. As the matter of fact, during the filling stage the coke drum falls into steady state condition.

In the cooling stage, quenched water is injected and cools the coke drum from inside. Decrease of temperatures with time of the shell is more rapid than the skirt. As a result, temperature of points T1 to T4 are now relatively lower than T5 to T7. In other words, the shell portion is colder than the skirt. However, there is an exception at point T8, which its temperature is lower than the shell portion. This is because point T8 contact with base which has surrounding temperature.

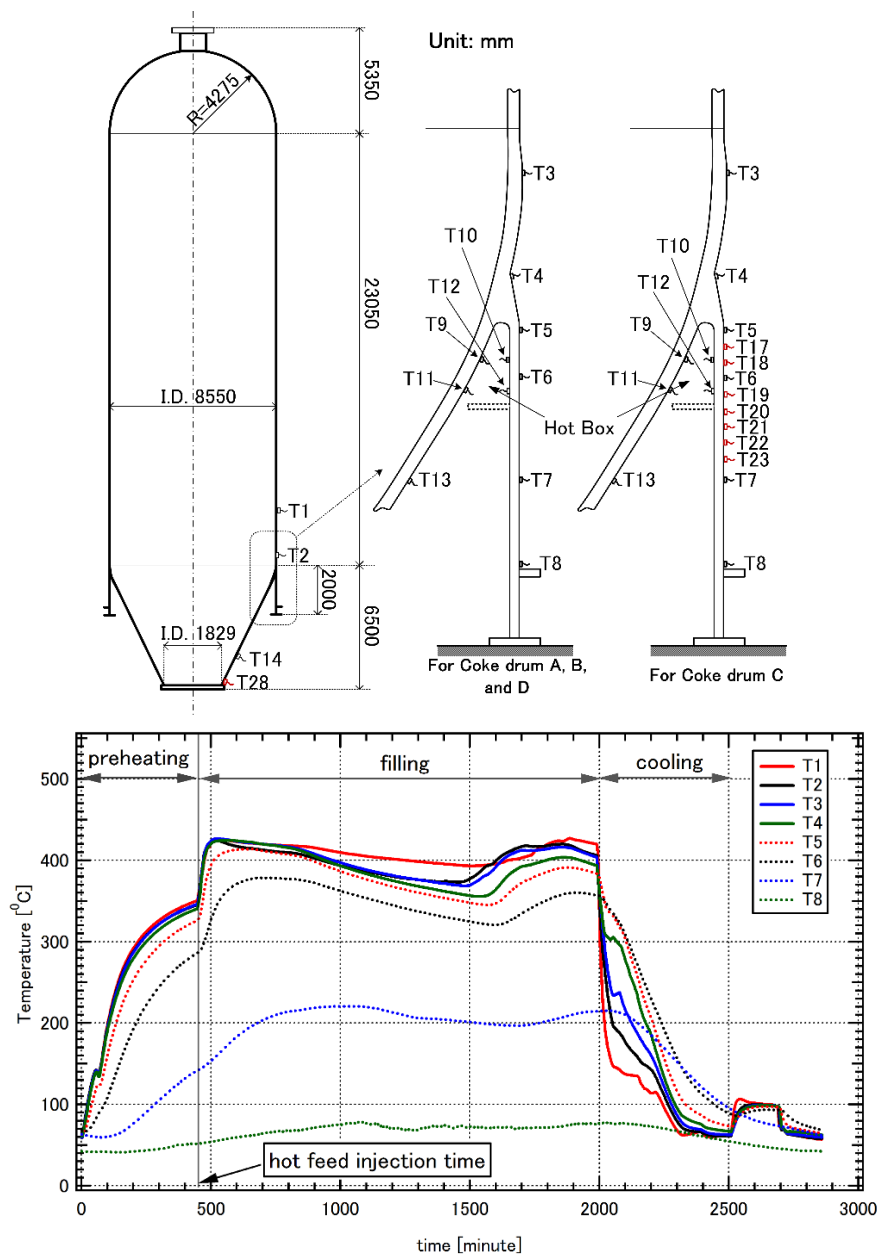


Fig. 1 Coke Drum and Typical Coke Drum Cycle

In the past ten years, the frequency and severity of these cycles dramatically increased while the cycle times steadily decreased from 12 to 24 hours and more recently to as low 10 hours cycles. As a result, coke drum with few or no previous problems began to crack through wall in the shell and/or skirt region. In addition, many new coke drums are cracking through wall in as few as four or five years because they are not designed for the more severe fatigue service in which they currently operated.

This paper focused on the coke drum operating cycle behavior. Some statement says that longer cycle will effect on longer fatigue life of coke drum, but it also occurred that the operational stages also plays an important role to prolong coke drum's fatigue life. Thus, this paper attempt to investigate some selected cycle of coke drum to understand the correlation between cycle period and the fatigue life of coke drum. The next attempt is to compare the cycle which can be categorized as normal cycle and another cycle which is assumed as a bad operation cycle due to very short cycle period.

2. Method

For this coke drum 28 thermocouples and 6 strain gauges are installed in the skirt attachment area as shown in fig. 2. Three pairs of the strain gauges are installed at points C4, C5, and C6 respectively. Each pair is aimed to measure strain in axial and hoop directions. More refined thermocouples were attached at the upper part of the skirt. The objective is to capture a more realistic temperature distribution.

Temperature boundaries at two measured points are assumed to be linier. Temperature variation in radial direction is assumed to be zero. Since the analyses is focused at the skirt area and it is convinced that temperature variations above point C1 do not strongly affect the skirt area. Thus, temperature of the coke drum above point C1 is assumed to be the same as temperature of point C1.

Coke drum material is considering by activating gravitational force in $-z$ directions. Here the coke drum material density of 7850 kg/m^3 is imposed. The weight of the coke and quenched water are considered. At the end of the cooling stage, the coke drum is filled by the coke and quenched water with a level which is assumed be 80% of its capacity. Here the height of the coke and water is assumed to be 25.6 m. this load is imposed as hydrostatic pressure in the inner surface. And the density of combination of coke and water is assumed to be 1481 kg/m^3 .

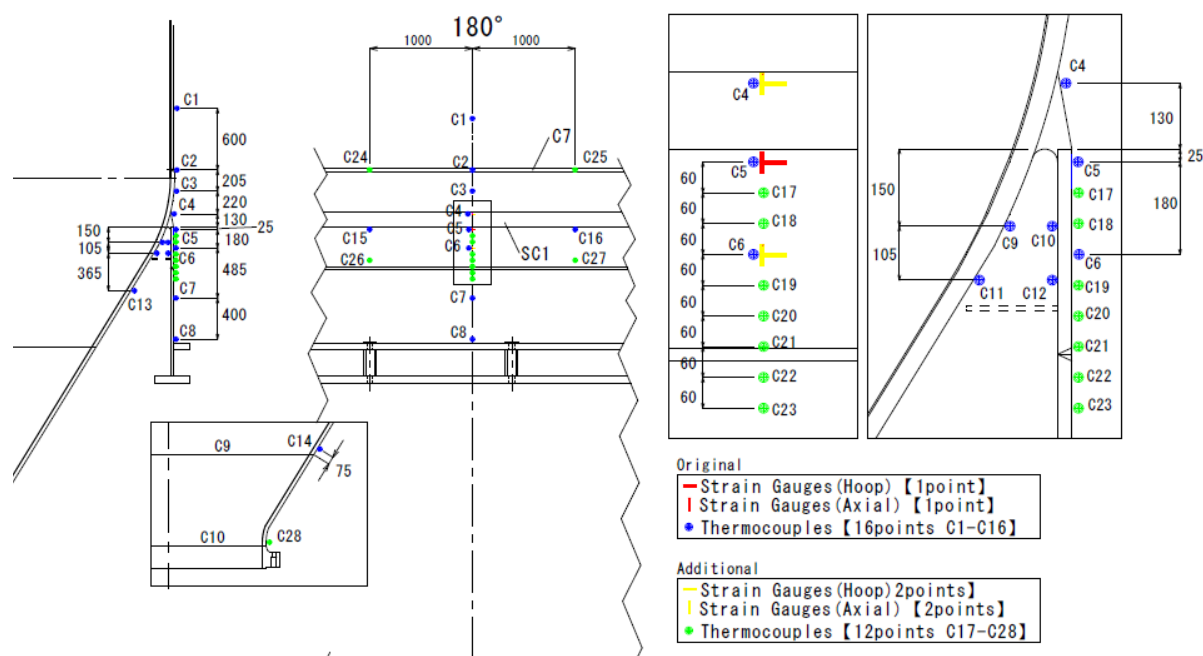


Fig.2 Location of Thermocouples and Strain Gauges in Coke Drum

Numerical analyses were performed by using ANSYS code [3]. The coke drum was analyzed by three dimensional model, which is developed based on fabricated drawing of the coke drum. The model and constrains are shown in fig. 3.

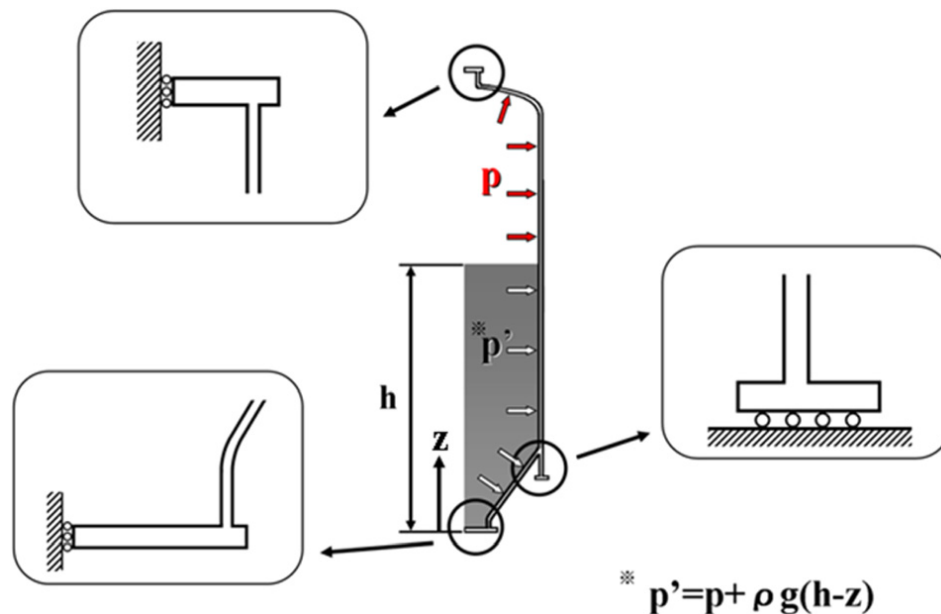


Fig. 3 Model of Structural Boundary

The coke drum and the skirt are made of low alloy steel SA-387 Gr. 11 CL. 2 (1.25Cr-0.5Mo-Si). The mechanical properties are obtained from ASME boiler and pressure vessel codes II section D. Young modulus (E), thermal conductivity (γ), and coefficient of thermal expansion (α) are temperature dependent and shown in table 1. Poisson's ratio is constant at 0.3.

The model for numerical analyses is half segment of the coke drum. There are two mesh model were tested in this simulation which is 25675 and 41351 nodes. The strain result is almost the same but for the better result the model with 41351 nodes was selected for analyses.

Table. 1 Temperature dependent material properties

Temperature (°C)	Properties		
	Young modulus (GPa)	Thermal Conductivity (W/mK)	Coeff.of thermal exp (°C)
0	205.5	41.05	-
25	204	40.9	0.0000116
100	200	40.6	0.0000121
150	197	40.4	0.0000124
200	193	40.1	0.0000128
250	190	39.5	0.0000131
300	186	38.7	0.0000132
350	183	37.8	0.0000135
400	179	36.8	0.0000139
450	174	35.8	0.0000142
500	169	34.8	0.0000143
550	164	33.9	0.0000146
600	157	32.8	0.0000148

3. Result and Discussion

As for numerical analyses validation, strain data which gathered from strain gauges is compared to the numerical result. The selected cycle have total time of 2771 minutes. Similar with the temperature plot history we can also divided the strain result to preheating, filling, cooling, and switching stage.

The comparison between the numerical result and measured data at point C5 is shown in fig. 4. The figure shows that, even though there are some differences between those results, the results of present numerical solution show the same trend and they do agree.

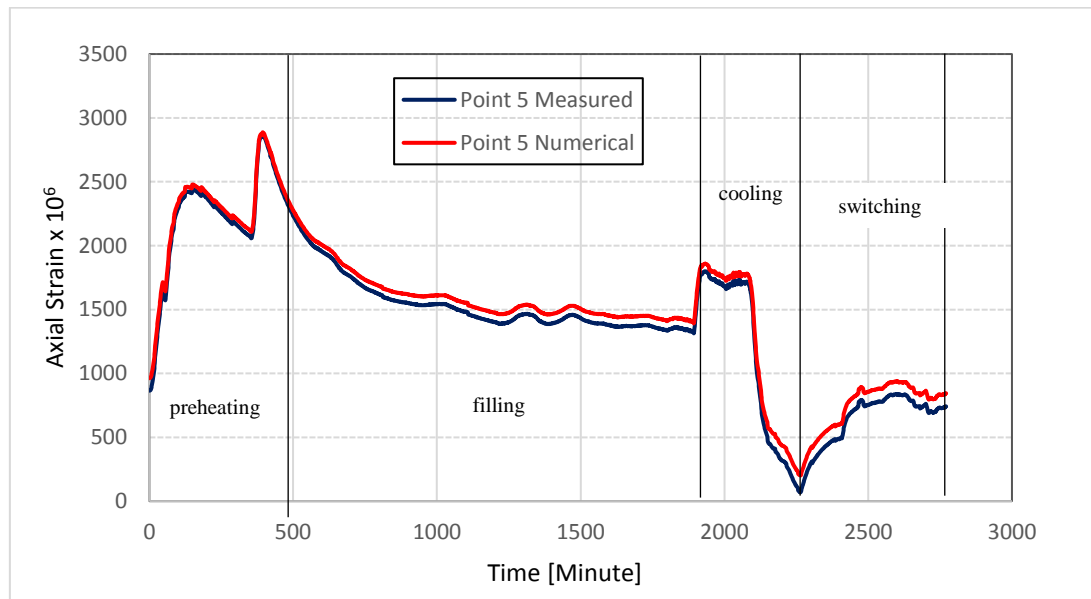


Fig. 4 Comparison of Numerical and Measured axial strains

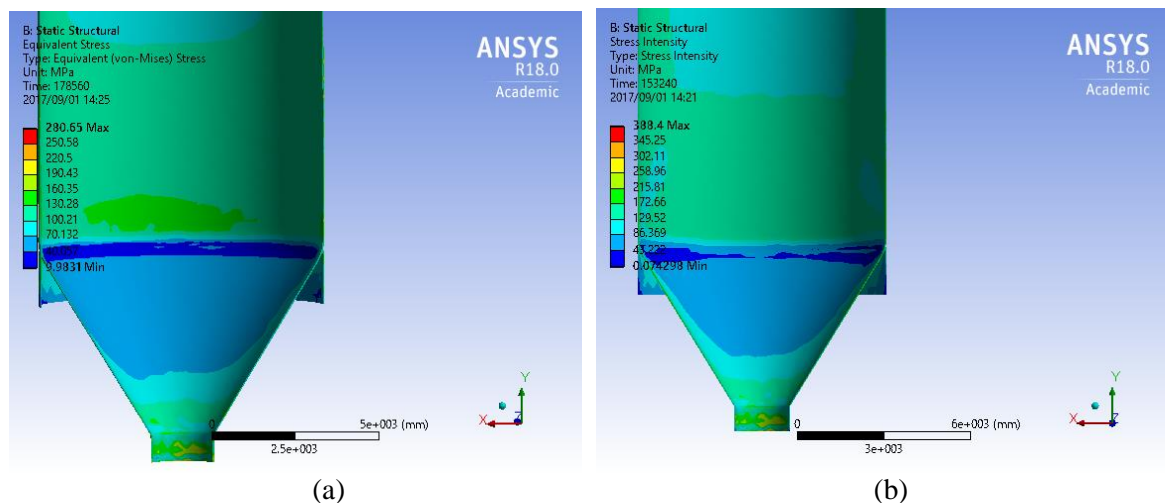


Fig. 5(a) Contour of stress intensity for normal cycle and (b) short cycle

After validating result between numerical and measured data, fatigue life estimation of some selected cycle will be performed. First is the cycle that can be categorized as the normal cycle with cycle period of 2976 minutes or we can call it as the normal cycle. Another cycle is the cycle that can be categorized as a bad operation cycle with cycle period of 2554 minutes, or we can call it as a short cycle.

In order to examine whether the skirt area falls into plastic deformation or not, contour of stress intensity from aforementioned selected cycles is shown in fig. 5. From the contour of stress intensity we found that with the normal cycle maximum stress is 292 MPa, fig. 5(a), and for the short cycle maximum

stress is 388 MPa, fig. 5(b). The highest stress intensity occurred in preheating stage, both for two selected cycles. From the numerical result it is found that, for the normal cycle stress intensity have a peak at minute 595. Than can be categorized as the switching stage from preheating to filling stage. The peak stress intensity of the short cycle is occurred at 320 minutes in preheating stage.

According to material data properties, the yield strength of SA-387 Gr. 2 CL.11 is 310 MPa. From this fact we can concluded that for the normal cycle, the stress peak is still tolerable because the peak stress is below the limit of yield strength of material. For the short cycle, stress peak is far exceed the yield strength of coke drum material. In this kind of cycle, the upper part of the skirt suffers from the most severe thermal stress and they fall into plastic deformation in the preheating stages. The main conclusion here is that for the selected short cycle can be categorized as a bad operation, and should be avoided to extend the useful life of coke drum.

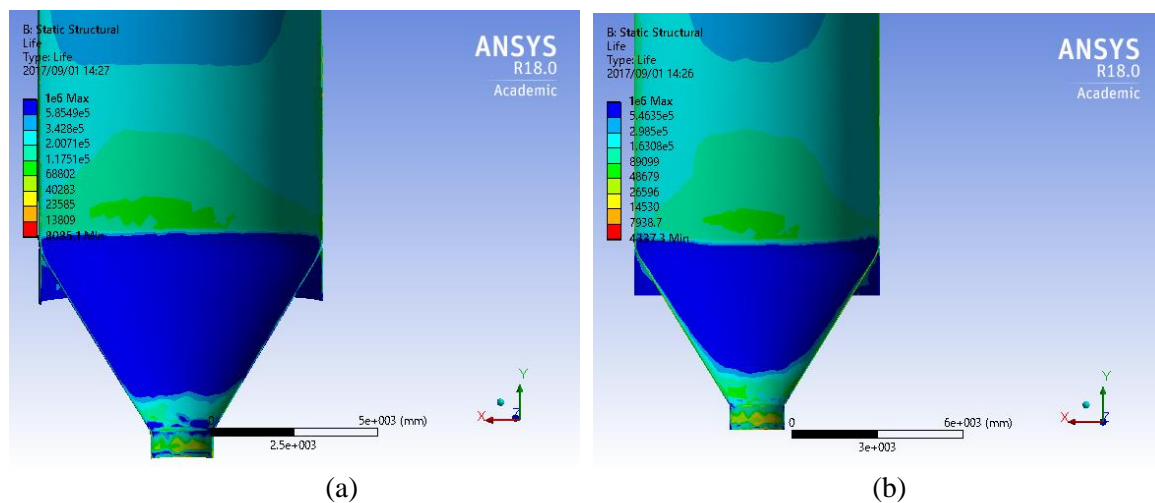


Fig. 6(a) Contour of Fatigue Life for Normal Cycle and (b) Short Cycle

From the contour of fatigue life in fig. 6(a) above we can see that the fatigue life estimation of coke drum for normal cycle is 8085 cycles and for the short cycle coke drum, the fatigue life estimation is decrease to 4333 cycles, almost the half compare to the normal cycle, shown in fig. 6(b). In the normal cycle, preheating stage with moderate rise in temperature gradient, generate a moderate thermal stress in the shell to skirt junction. However, for the short cycle the short cycle period produce a higher temperature gradient in the preheating stage. Effect of the cycle period will be discussed in the next paragraphs.

As the aforementioned before, in the preheating stage temperature rise first in the shell portion of the coke drum. From the coke drum picture, we can see that the connection between the shell portions to the skirt of the drum is only the small part of the junction or we call it the shell to skirt junction. Thus, in the preheating stage the heat transfer from the shell part to the skirt part is merely conduct only by the conduction heat transfer of the junction. This is causing a high temperature difference between the shell and the skirt part which generate high thermal stress [4].

Actually some research have been implemented to try to reduce the high temperature difference between the shell and the skirt portion of the drum. One of the research focused on the attachment of hot box in the shell to skirt junction area to enhance heat transfer due to the generation heat transfer. Nevertheless, the result show that the natural convection have only a small part to enhance the hat transfer in the shell to skirt junction area or only around 10% for the total heat transfer [5]. Thus new method to enhance the heat transfer in shell to skirt junction need to be developed.

For further understanding about the mechanism of thermal stress in the coke drum, temperature plots for two selected cycles which were taken from point C5 is shown in fig. 7. From the temperature plot we found that the average temperature gradient in the beginning of preheating stage is 1.3°C/minute for the normal cycle, and 1.2°C/minute for the short cycle. Thus, we can concluded that in the beginning of

preheating stage, there are no significant differences between these two cycles. However, between preheating stages to the filling stage for the short cycle there occurred a temperature leap at minute 319 to minute 320, from 310°C to 410°C. At this time, temperature inflation is around 100°C. This fact also show that the stress peak occurred in the same time of the occurrence of the temperature leap.

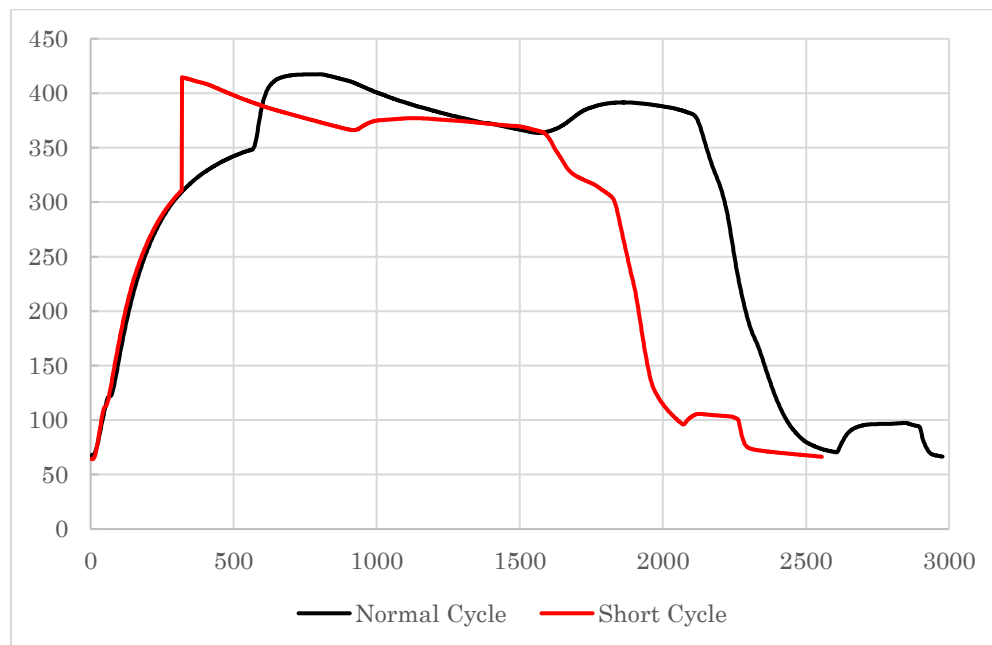


Fig. 7 Temperature plot for Normal Cycle and Short Cycle

The sudden change in temperature can caused a sudden change in stress rate due to thermal stress, called thermal shock. In thermal shock the rate application of the stress is very rapid. In some ways, the thermal shock also affected material to become brittle material by rapid application of stress and therefore may not be able to withstand a thermal-shock stress which they could readily absorb if it were slowly applied [6]. Even though the coke drum material SA-387 Gr. 11 CL.2 is categorized as a ductile material, but under repetitive application of thermal stress, the coke drum material can fall into brittle due to plastic deformation, work hardening and accelerate the thermal stress fatigue of material.

The cycle behavior have the important role to determine the fatigue life of the coke drum. As the aforementioned before, the sudden temperature increasing due to the bad maintaining during the cycle period can reduce the life span of the coke drum by a half, compare to the normal cycle. Thus the optimization of the cycle behavior have an important role to prolong the fatigue life of coke drum and need to be implemented.

4. Conclusion

In this research, numerical analyses to estimate fatigue life of coke drum have been implemented. It was found that the numerical analyses and measured data have a good agreement when it compare the strain result.

Two kind of cycles have been observed, which are categorized as normal cycle and short cycle. Two kind of cycles have been observed, which are categorized as normal cycle and short cycle. From the normal cycle it was found that the fatigue life of coke drum is 8085 cycle and the fatigue life of the short cycle is 4333 cycle, according to numerical analyses.

There is a significant fatigue life deflation for the short cycle compare to the normal cycle, which assumed because of the high stress peak in that occurred in the preheating stage of the short cycle that exceed the yield strength of coke drum material. This happened due to the leap of temperature in the preheating stage that caused a thermal shock and turn the upper part of the skirt area of the short cycle into plastic deformation and accelerate the thermal stress fatigue. For the aim of longer life span of coke drum material it can be concluded that the cycle optimization and behavior is have an important role to

control the cycle in moderate rise of thermal stress and avoid the thermal shock.

References

- [1] ASME 2007 ASME Boiler & Pressure Vessel Code, Section II, Part D, Properties-Material (ASME)
- [2] Oka A, Ambarita H, Daimaruya M, Fujiki H 2011 Study on the effects of switching temperature on the thermal fatigue life of the shell to skirt junction of coke drum *ASME Pressure Vessel Technology* 133
- [3] *ANSYS Fatigue Module* 2006 ANSYS, Inc
- [4] Zihui Xia, Fengju, Pierre Du Plessis 2010 Heat Transfer and Stress Analyses of Coke Drum for Complete Operating Cycle *ASME Journal of Pressure Vessel Technology* 132
- [5] S Andrey, Ambarita H, Daimaruya M, K Hideki Transient Natural Convection and Conducting Heat Transfers on Hot Box of a Coke Drum in Pre-heating Stage IOP Conf. Series: Journal of Physics. Series 801
- [6] S. S Manson 1966 *Thermal Stress and Low-Cycle Fatigue* (McGraw-Hill) p 3