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APPLICATION OF ELASTIC-PLASTIC METHODS TO DELAYED COKER DRUM DESIGN

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ABSTRACT

Coke drums are pressure vessels that are used in oil sands and conventional refinery processing industries for the thermal cracking of reduced bitumen to recover additional, saleable gas and liquid product streams. The drums are constructed to the requirements of ASME VIII Division 1 although they are in a low cycle thermal-mechanical service environment. Recent practice has been to introduce design by analysis considerations from ASME VIII Division 2 even though service temperatures of the actual equipment exceed the design limits of the Code. In this paper, simplified elastic-plastic analysis models are developed for assessment of the stress and strain levels in coke drums during specific operational phases. One model is applied for determination of the local stress caused by differences in the coefficients of thermal expansion between the clad liner and base materials. Because clad construction is used throughout the vessel, the impact is extensive. Consideration is given to the general stresses induced by the cyclical, progressive dilation and contraction action of the drum shell caused by axial thermal gradients. Another model estimates hot and cold spot formation and the development of localized stress / strain distributions in coke drums. The resulting thermal stresses include the local stress from suppression of differential expansion between clad and base material, thermal bending stresses and local thermal stresses from hot and cold spot formation. It is found that the evaluation of these loads on drum cracking aligns with industry survey results. Better understanding of these loads has impact on materials selection and fabrication procedures for new drums and repair of existing drums. Operational considerations can also be identified to help improve drum reliability.

INTRODUCTION

The importance of delayed coking units [DCU] continues to increase as reliance on heavier crude oils gains momentum in the hydrocarbon processing industry. Coking capacity is expected to grow by 3.3 MBPD in the period 2005 – 2020 [1], and heavier crudes are predicted to account for 50% of global oil supply by 2030 [2]. The essential equipment of a delayed coking unit consists of a fired heater which heats the residual oil feed to temperatures at which thermal cracking initiates, the coke drum where disengagement of vapour and solid factions occurs and the remnant carbonaceous material or coke is collected, and the fractionator where saleable hydrocarbon products are recovered. A typical process circuit is shown in Figure 1 which illustrates a 2 drum configuration since the unit operates in a batch-continuous mode. The coke drum is subjected to severe thermal cycling; and, experiences temperature changes from ambient to 900 °F [482 °C] during a fill sequence extending over a time period from 12 to 24 hours. At the end of this fill sequence, a rapid steam quench is followed by a longer water quench which cools the remnant material to a safe temperature but which mechanically strains the drum shell. Maximum operating pressures [MOP] extend from 35 to 50 psig [241 to 345 MPa], in cyclic manner from 0 to MOP, over the full operational cycle. The modern coke drum has been in service since 1938 [3] and drum shell bulging and cracking have been documented since the 1950's [4]. Coke drums are usually constructed according to the requirements of the ASME boiler and pressure vessel Code, specifically ASME Section VIII Division 1 [5] or comparable international documents. Although drum and skirt cracking have been an unresolved reliability issue, the success of the Code construction is apparent as jurisdictions regularly register DCU coke drums to Division 1 rules. Recently, designers and investigators have referenced application of the design-by-analysis rules of ASME Section VIII Division 2 in order to evaluate and further, to identify improvement in design [6] [7] [8] [9].

This paper provides additional characterization of the thermo-mechanical fatigue loading occasioned by the operational loads imposed on a typical DCU coke drum and