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Design Guideline Strategies for HPHT Equipment

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Abstract

As the need for oil and gas equipment working in hotter and higher pressure environments continues to mount, the effort to come up with an adequate set of design, material, and validation practices continues to be challenging. The higher pressures, and therefore thicker wall sections, have pushed traditional thin-wall pressure vessel design practices to theoretical limits, where their design model assumptions are becoming increasingly inaccurate in predicting design stress or present overly conservative hardware designs that are too thick or complicated to fabricate; not to mention safely pressure test in the factory. Manufacturing processes and material mechanical properties are also being pushed well beyond general practice to meet more stringent ductility requirements and to resist aggressive corrosion environments. Historically, designers simply overdesigned the equipment to provide a robust product with liberal design margins to hopefully out-muscle any unforeseen or complicated set of loading conditions. However, for the newer HPHT oilfield equipment, overdesign is less and less an option. Now the most challenging design failure mode is shifting towards fatigue and fast fracture as the equipment is taxed by very high internal pressures, while increasing temperatures are decreasing material strength. As a result, more rigorous stress analysis and design methods that more closely model fast-fracture burst conditions (rather than leak-before-burst failure) are needed to achieve safe, reliable and cost effective equipment designs. However, the effort to fully embrace the change to more rigorous design methods has been arduous. The Industry is just entering the transition zone between conventional and HPHT environs, and pressure vessel code "demarcation" on pressure ratings overlap in this region. Therefore a lengthy debate has ensued as to where does one draw the line between traditional "quasi-static" (infinite fatigue life) thin wall pressure vessel design practices and begin using a Lamé thick-walled model with fatigue and fast-fracture failure (fracture mechanics) design practice. Both have equally valid arguments in this transition region from 10 000 psi at 250F to 20 000 psi at 400F (69 MPa at121C – 138 MPa at 205C). Some of the debate on where the line of demarcation is drawn is fueled by the fear that when one crosses that line, then fatigue/fracture mechanics will drive design calculations, material performance and testing, and validation testing exponentially beyond what is expected today.

Although this Rubicon will eventually have to be crossed as HPHT conditions tax designs and materials, this paper offers some insight into some simple tests to augment HPHT design practices, building on the insights presented in OTC paper # 23621.

Introduction

The path toward designing oilfield High Pressure High Temperature (HPHT) Wellhead and Tree equipment is slowly crystallizing as Industry and Regulators show increased interest and angst in developing and reviewing pending projects and approving investments in long term assets. There are three significant roadblocks in the path to a workable solution: no clear HPHT design methodology, lack of understanding of what tests will validate designs, and very little published material properties data at HPHT conditions. And the scope of all three is exacerbated over the debate whether fatigue and fracture mechanics should be part of the equation. As oilfield equipment is subjected to more severe and longer periods of cyclic forces (internally from irregular wellbore flowing conditions, or externally from metocean conditions), many agree that fatigue life and monitoring for these conditions has to be a part of the design equation. And this fact is mentioned in the ASME Boiler and Pressure Vessel Code recognizing the two failure modes of a pressure vessel: leak-before-burst, or a fast-fracture burst. The second failure mode vexed the engineering community until the advent of fracture mechanics and better theories of crack initiation, growth and eventual plastic collapse through the wall of the pressure vessel.