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Effect of Wedge and Crescent Wear on Production Tubing Burst Pressure Rating

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Abstract

This paper presents the effect of wedge- and crescent damages on the tubular burst pressure. The analysis is based on analytical API Barlow model and finite element method (FEM). The analytical model does not consider the worn out part, whereas the FEM includes the defect as part of the analysis.

Results showed that for uniform walled tubular, the FEM and the API Barlow model pressure predictions are nearly equal. As the single and the double crescent wear depth increase from 0 to 50%, the API Barlow model over predicts the FEM burst pressure in range 1 - 44% and 2-50%, respectively. Likewise, for the single – and the double wedge wear, the API modeling percentile deviations from the FEM results are 1-57% and 2-58%, respectively. The overall analysis indicates that FEM is a reliable modelling approach for flaw included tubular.

1 INTRODUCTION

NORSOK D-10's design criteria mainly deals with loading and quality material selection. The casing shall be of a higher quality that can withstand particularly corrosive media in the well (H_2S, CO_2, etc…), if they exposed to such environments. The standard also demands that the casing shall be designed with respect to realistic load conditions during the life time of the well. The loads shall be corrected for additional loads and effects such as:[1] Casing wear, bending in a deviated hole sections, temperature effect, corrosion, plastic formations and reservoir compaction, pressure during completion, workover and kill operation.

Petroleum Safety authority (2004) [2] performed a well integrity survey on 75 injection and production wells. The survey result showed that 39% of the integrity problems were associated with tubing.

During drilling and well operations, casing and tubing are exposed to several loadings. The mechanical friction between casing and drill string, tubing and coil tubing leads to wear. In addition, corrosion is also a critical problem in petroleum and other industries.

Based on the nationwide report in the USA, corrosion in the oil and gas production and manufacturing industry alone cost US$1.4 billion per year. [3] During reservoir productivity enhancement jobs such as; coiled tubing, acidization, seawater and CO_2 injection, the tubing experience corrosion. In Dutch sector of the North Sea, case studies indicated that 25% of CO_2 injection wells experienced tubular degrading [4].

In Gullfaks A-42, the measured casing wear indicated that about 30% of the wall thickness had been removed [5]. This was due to drill string connections and casing interaction as well as hydrodynamic fluid flow. In addition, one of the operators in the North Sea measured 47% wall thickness reduction of production tubing [6]. These illustrate that tubular wear is a critical problem in drilling and production wells.

Commercial tubular design and analysis tools do not consider local tubular damage as part of the analysis. The softwares are developed based on uniform wall thickness cylinder theory. During well stimulation, gas lift, tubing and casing pressure testing operations, damaged tubular experiences excessive loads. As a result, the loading may lead to tubular failure. In order to avoid or mitigate tubular integrity problem, it is important to continuously monitor the condition of tubulars and redesign the collapse and burst derated pressure based on the severity of the tubular damage.

This paper will therefore analyze the application of API Barlow model calculation for redesigning wear included tubular and compare the result with the FEM method.

2 THEORY

The three tubular failure mechanisms are collapse, burst and axial (buckling or tensile). It is important to determine the safe operational windows to avoid tubular dysfunctionalities. The API burst model (also known as Barlow's equation) is derived based on uniform thin walled cylinder theory and the model reads [7]:

$$P_y = Tol.\frac{2\sigma_y.t}{OD} \tag{1}$$

Where, t and OD are the wall thickness and outer diameter and σ_y is the yield strength. The API model includes tolerance (Tol.) for wall thickness a factor of 0.875.

3 FINITE ELEMENT MODELING

ABAQUS/CAE is a popular structural engineering design and analysis tool. The simulation of any physical phenomenon, including tubular wear, is performed by ABAQUS/CAE, using the numerical technique called Finite Element Method **(**FEM**).**

3.1 Case scenario

Tubulars may have damages of different size and shape. However, for the evaluation and quantification of derated burst pressure, two ideal damage shapes were considered. These are:

- **Case 1**- Single - and double crescent shape wears (**Figure 1**). The assumption is that due to coil tube and production tube interaction, the mechanical and hydraulic forces create crescent shaped damage on production tube.
- **Case 2**- Single - and double wedge shape wears (**Figure 2**). The case scenario assumes that pitting corrosion can create wedge shape damage. Moreover, during drilling, the interaction between drill string and casing in the presence of cutting may cause an irregular shaped defect such as wedge.

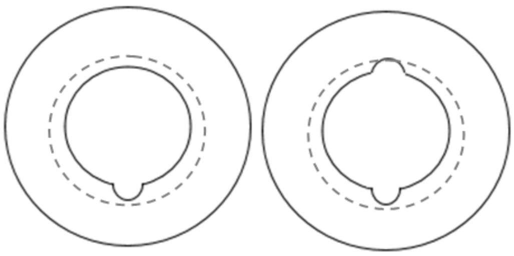

Figure 1: Crescent shape damage

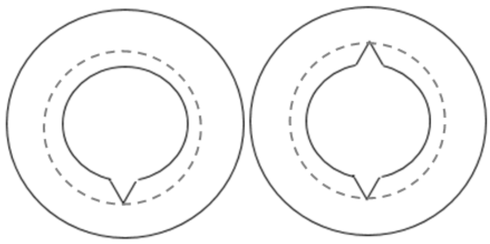

Figure 2: Wedge shape damage

The analytical calculation using API burst (Eq. 1) is performed by uniformly removing the regions bounded by the dotted circular surfaces along with the damage parts. On the other hand, the FEM modelling approach includes the local damages as part of the analysis without removing the surface uniformly. The results obtained from the two methods will be compared.

3.2 Simulation setup

The FEM modeling technique in short is by building geometry, meshing the geometry, assign material properties, define boundary condition, applying load and finally solve the problems.

Material Properties:

L-80 grade is a widely used production tube and was selected for the simulation. The mechanical and physical properties of the tube are provided in **Table 1**.

Table 1: L-80 tubing elastic and geometry parameters

Parameters	Value
Grade	L-80
Outer diameter	5.5 inch
Inner diameter	4.892 inch
Youngs modulus	$30x10^6$ psi
Poisson ratio	0.25

Boundary condition:

The internal and external pressures loading deform the string in the axial, circumferential and radial directions. The boundary condition is therefore assumed to be free at the top and the bottom ends of the string.

Loading:

The tube is loaded externally with the completion fluid, which is constant until gas lift operation is being activated. For burst pressure modelling, the internal pressure was varied until the von Mises stress in the tubing reaches to the yield strength. The derated pressure is used to redesign the safe operational window for loadings such as production, shut-in, bull-heading, hydraulic fracturing and well stimulation.

4 RESULTS AND DISCUSSION

As previously mentioned, the primary purpose of the simulation study was to examine the effect crescent, and wedge shape damages along with wear depth on the burst strength of tubing. The wear percentage in this paper is defined as the wear depth relative to the wall thickness of the tubing.

4.1 Stress field in worn and uniform tubing

To investigate the application of the industry method of derating burst pressure, first the stress fields in the damaged and wear removed tubular was studied. The width and 25% wear depth were assumed to be equal. The models were loaded at the inner and external pressures with 3500psi and 727 psi, respectively.

Figures 3-5 show the simulation results of the uniform and locally damaged (crescent & wedge) tubulars. As shown, the higher stress is concentrated at local wear compared to the

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undamaged tube exhibited a uniform stress distribution. The comparison as provided in **Table 2** shows that the von Mises stress concentration at the localized crescent and wedge defects were 25% and 64% higher than the uniform damaged tubular. This indicates that the application of API Barlow model by removing the damage part is not a reliable approach.

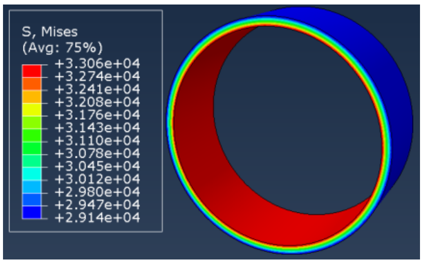

Figure 3: Uniform surface

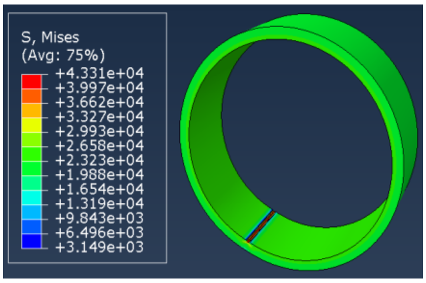

Figure 4: 25% Crescent

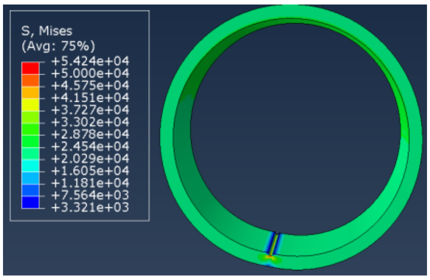

Figure 5: 25% Wedge

Table 2: Simulation results comparison

Geometry	von Mises, kpsi	% Change
Uniform	33.06	-
Crescent	43.31	25
Wedge	54.24	64

4.2 Base case- Uniform wall thickness tubing

The base case scenario was designed to compare the analytical API Barlow's equation (Eq. 1) with the FEM. For the base case calculation, the wall thickness of the tube was removed uniformly from initial radius (r_i) to the final radius (r_f), which was obtained by removing 50% of the wall thickness (**See Figure 6**). **Figure 7** shows the T-95 tubing (ODxID=4.0″x3.548″) derated burst pressure simulation results. As shown in the **Figure**, the FEM simulation nearly captures the analytical API burst model result. The base case simulation clearly illustrates the trustworthy of the numerical method and the applicability of the API model for a uniform walled tubular.

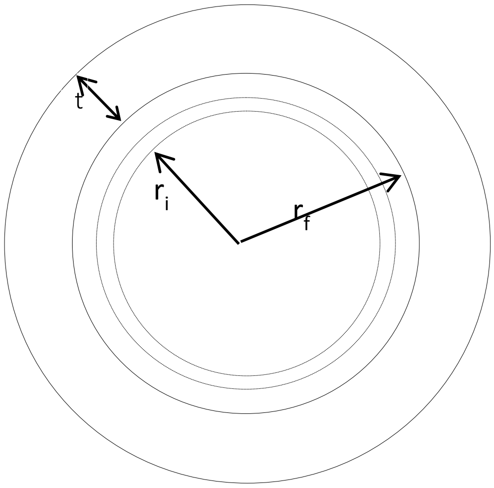

Figure 6: 50% of tube thickness at inner surface uniformly removed

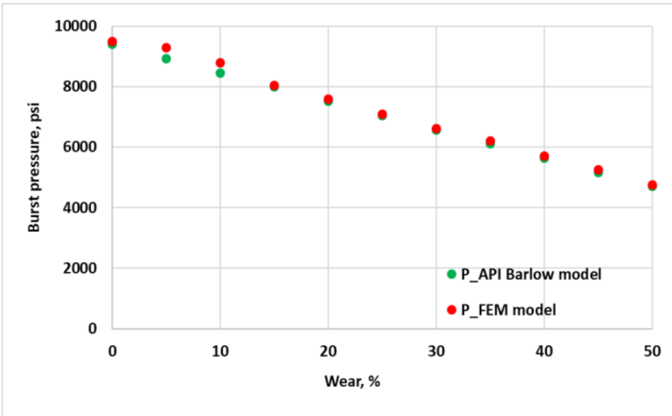

Figure 7: Uniform wall thickness tubing burst de-rating pressure comparisons between API Barlow and EFM modeling.

4.3 Effect of crescent and wedge shaped wear tubing burst pressure

The derated burst pressures of the single and the double worn out tubulars sketched in **Figures 1 and 2** were simulated and the results are presented in **Figure 8**. As shown, up to 15% wear, both the single and double crescent damages are nearly equal and show deviation afterward. On the other hand, the two wedge shapes show nearly the same derated pressures.

Results also show a significant difference between the API Barlow- and FEM based derated burst pressure predictions. As the wear depth increases, the burst pressures decrease linearly and non-linearly, respectively. For instance, for 30% of wall thickness worn out tubing, according to API Barlow model, the 4000 psi does not cause tubular failure, but the EFM model predicts the tubing would burst.

Figure 9 displays the difference between the Barlow's model and the FEM based results presented in **Figure 8**. As the wear increases from 0% to 50%, Barlow's model prediction deviates from the double wedge and the double crescent shaped wear FEM models over predicting up to 3015 -and 2600 psi, respectively

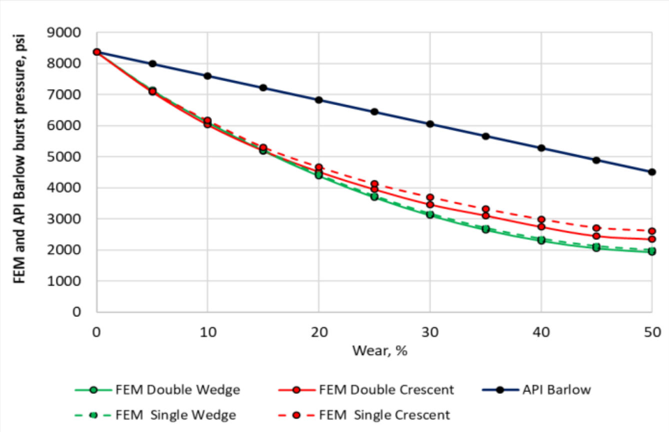

Figure 8: Comparison of tubing burst derated pressures of L-80 tube.

Further, for better assessment, the pressure differences presented in **Figure 9** were converted to percentile with respect to the API model prediction. As shown in **Figure 10**, the analytical model prediction deviates from the single -and double wedge FEM models in the range of 1-57% and 2-58%, respectively. Similarly, the analytical model over predicts the single -and double crescent included FEM results by 1% to 44% and 1% to 50%, respectively.

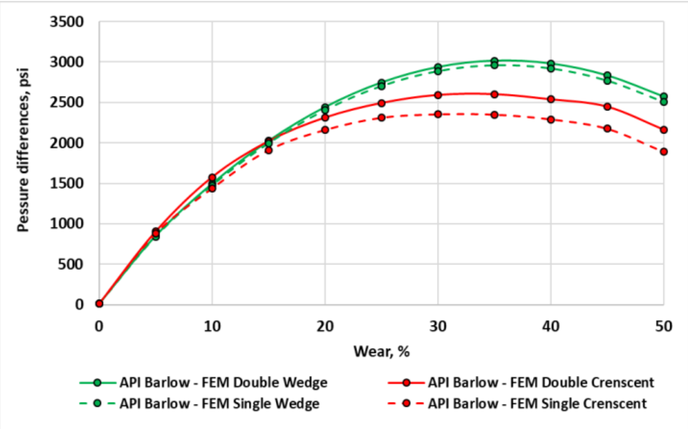

Figure 9: Tube burst derated pressure difference between Barlow's model- and FEM model predictions of L-80 tube.

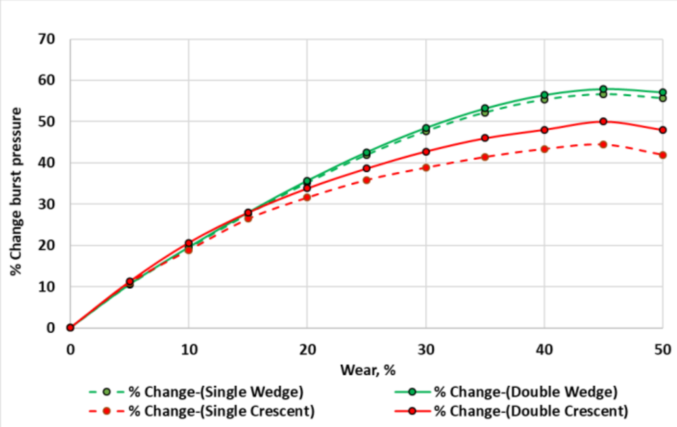

Figure 10: Percentile deviation between API Barlow and FEM predictions.

4.4 Limitation and application of this work

The modeling and analysis is valid for the considered external pressure loading, and 5.5″ (OD) x 4.892″ (ID) L-80 grade tubing. As the external pressure increases, the internal burst pressure is also increasing. However, the differential pressure across tubing remains the same.

The work did not take the temperature and the bending effects into account. However, these need to be coupled for better prediction and understanding.

5 SUMMARY

Prediction of accurate operational loading on tubular is a key for structural integrity. During the life time of a well, the tubulars experience several loadings and corrosive environments. This may introduce defects in tubulars and result in deteriorating the load carrying capacity of the structure. In this paper, the effect of wedge and crescent shaped scars on the burst pressure rating were simulated.

Results from the simulation setups can be summarized as:

- As wear increases from 0% to 50%, the deviation of Barlow's prediction from single and double wedge FEM models increases from 1% to 57% and 2% to 58%, respectively.
- Similarly, Barlow's prediction deviates from the single and double crescent from 1% to 44% and 1% to 50%, respectively
- Since the stress concentration at local damage is higher than the uniform walled tube, the applicability of Barlow's model needs to be revisited for worn out tubing.
- For the wear depth in the range of 0-15%, the single -and the double crescent and wedge damages show nearly equal tubing burst pressure.
- For undamaged uniform wall thickness tubular, both FEM and Barlow's burst pressure predictions are the same.

Since tubular analysis with commercial software is based on a uniform wall thickness cylinder theory, the study presented in this paper suggests the importance of a FEM based modeling approach for worn out tubular.

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