

WHITE PAPER

Casing Wear:

Causes, Prediction and Prevention

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During the drilling phase, the most costly component is casing. On top of the expensive casing materials and the costs likely to be encountered in cutting, pulling and replacing a worn or damaged string, casing wear creates more serious problems for operators due to its potential catastrophic incidents such as oil spills, blow outs or loss of the well.

I. Causes of Casing Wear

To analyze the forces behind casing wear, we need to study the torque and drag (T&D) of the drill pipe during drilling operations. The basic mathematical and physical model of T&D has not changed significantly since Johancsik et al. published their paper on T&D prediction. Any pipe movement in the deviated wellbore produces T&D along the pipe. Basically, axial movements such as drilling ahead or tripping creates drag, while rotation produces torque. The magnitude of T&D is determined by the combination of these two movements. While a tripping operation causes drag, pipe rotation shifts the resistance from drag to torque.

Since the so-called vertical well virtually does not exist (the whirring action of the bit always creates a micro-helical shape of the well path), the contact of the drill pipe and its tool joint with the casing ID is unavoidable. The gravitational force acting on the drill pipe is always trying to pull the pipe to the lower side of the wellbore, while the axial tension on the drill pipe, in a build-up section, tends to push the pipe to the upper side of the wellbore. Depending on the pipe weight, dogleg severity, and axial force along the pipe, the drill pipe either touches the upper or lower side of the wellbore.

Typical T&D analysis starts by dividing the pipe into small elements. Calculation begins from the bottom element of the pipe, where weight on bit (WOB) and torque on bit (TOB) are expected. For each element, force and torque are balanced and the T&D at the top of the element are calculated. From bottom to top, calculations are performed for each pipe element, until it reaches the rig floor. This step-by-step calculation also determines the direction and magnitude of the side force, which pushes the drill pipe against the wellbore as shown in Figure 1.

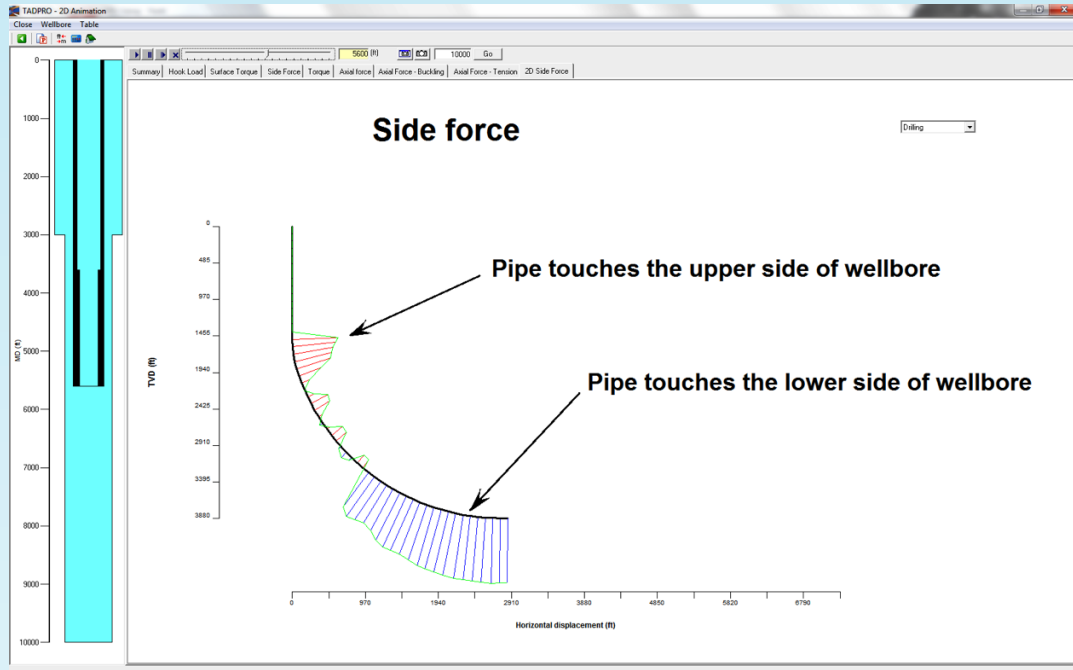


Figure 1. Snapshot of Side Force along a Drill Pipe

Under this side force, the rotating tool joint on the drill pipe against the casing inside, gradually removes steel from the casing wall and forms a crescent-shaped wear on the casing as shown in Figure 2.



Figure 2. Rotating Tool Joint Wears Crescent Grooves in Casing

The seriousness of friction between two contacting surfaces is dependent on the nature of rubbing surfaces and mud.

The tool joint coating plays a bigger role here compared to the casing wall. The industry has seen tool joint coating evolve from “casing killer” (rough tungsten carbide) to “casing friendly” as shown by many high-tech hardbanding materials.

Tungsten carbide applied on tool joint, while a very good protector of the tool joints, aggressively wears casing, so much that mud type and its additive will not help much in reducing casing wear if rough tungsten carbide is present.

Once a casing friendly tool joint coating has been selected, mud type and its additives play an intermediate role in casing wear. Water-based mud causes twice as much casing wear as the oil-based alternative. Lubricant reduces friction and severity of wear.

Generally speaking, high dogleg will create high side force and severe casing wear. The wear profile resembles the shape of dogleg severity. Higher RPM and lower ROP make more rotation time between the tool joint and casing and will cause aggressive wear.

In short, the following conditions contribute to casing wear:

- Well path and dogleg
- Drill pipe weight
- Tool joint coating
- Mud and its additive
- RPM and ROP

II. Prediction

1. Wear Mechanism

The casing wear model applied in [CWPRO](#) (casing wear prediction software developed by PVI) assumes that the metal volume worn away in a wear groove section is proportional to the frictional energy transmitted to the casing by a rotating tool joint as shown in Figure 2.

The transmitted frictional energy is defined in this formula:

$$E = \mu \times SF_{ij} \times SD$$

Where:

E = Frictional Energy, lb-ft

μ = Friction factor, dimensionless

SF_{ij} = Side force on tool joint per foot, lbf/ft

SD = Sliding distance traveled by the tool joint against casing wall, in

The volume of casing wall removed per foot in time t hours is mathematically expressed in the equation:

$$WV = WF \times SF_{dp} \times \pi \times D_{ij} \times 60 \times N \times t$$

Where:

WV = Casing wear volume per foot, in³/ft

WF = Wear factor, E-10psi⁻¹

SF_{dp} = Side force on drill pipe per foot, lbf/ft

D_{ij} = Tool joint OD, in

N = Rotary speed, rpm

t = Rotating time, hr

For a typical water-based mud, WF can vary as follows:

Normal or low: 3 – 7

Medium: 8 – 13

High: 14 – 20

WF above 20 can be considered as very high and may cause severe casing damage.

2. Wear Geometry

A typical wear groove is shown in the following figure.

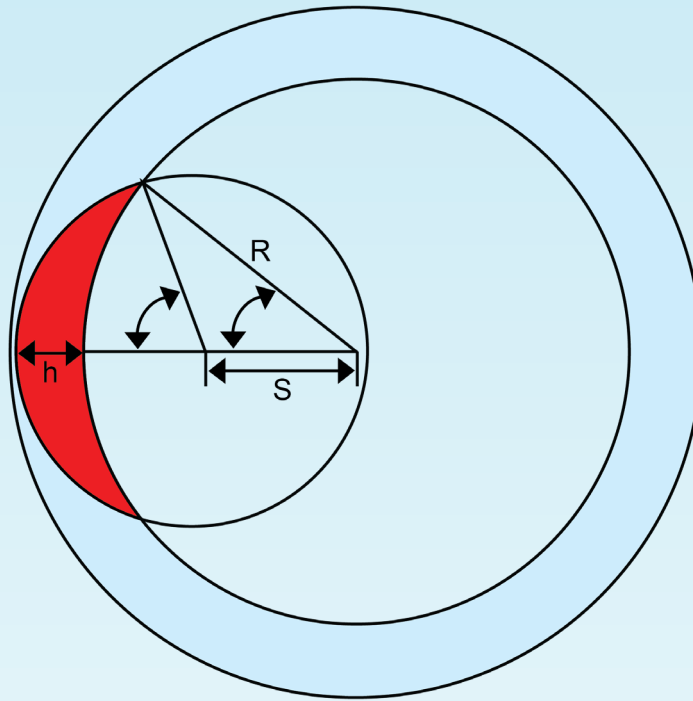


Figure 3. Casing Wear Groove

The relationship between wear depth and casing wear volume is:

$$WV = 12(\beta r^2 + 2\sqrt{P(P-R)(P-r)(P-S)} - \alpha R^2)$$

Where:

WV = casing wear volume per foot, in³/ft

h = wear depth, in

r = tool joint outer radius, in

R = casing inner radius, in

S = R - (r - h), in

P = (R + r + S) / 2, in

$$\cos \alpha = (R^2 + S^2 - r^2) / 2RS$$

$$\beta = \arctg\left(\frac{R \times \sin \alpha}{R \times \cos \alpha - S}\right)$$

3. Wear Factor

The definition of wear factor is the ratio of friction factor to specific energy, which is the amount of energy required to remove a unit of steel. The unit for wear factor is $E-10\text{psi}^{-1}$; therefore, when a wear factor is reported as 8, the actual value used in casing wear calculation is $8E-10\text{psi}^{-1}$.

Quite a few experiments were conducted to find the casing wear factors under different mud systems, tool joint materials, casing interior and drill string protectors. Among them, Maurer Engineering Inc. conducted a joint-industry project DEA-42. It was reported that more than 300 laboratory tests were performed under DEA-42 to determine the wear factors for various drilling conditions.

The following is a schematic drawing of a casing wear testing machine.

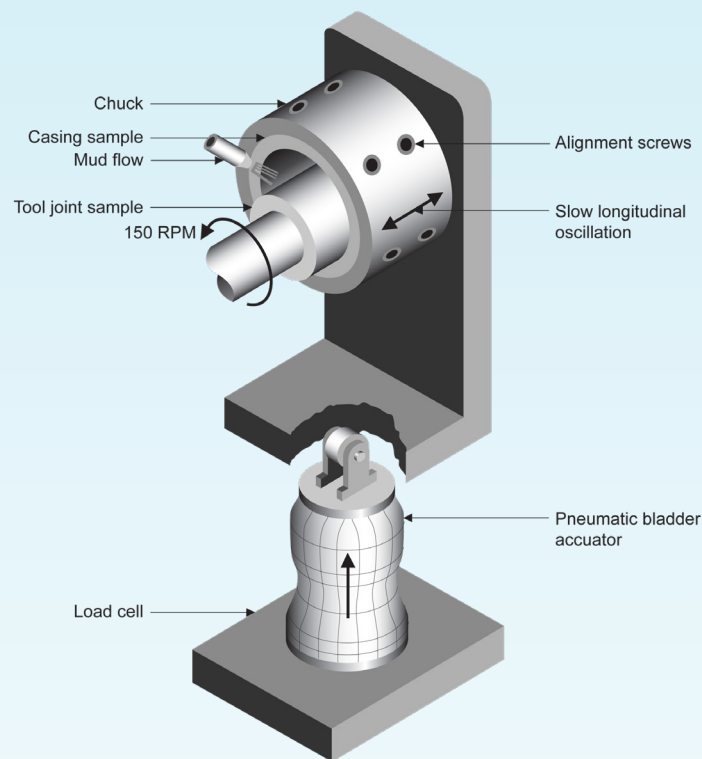


Figure 4. Casing Wear Testing Machine

In their Paper “Recent Advances in Casing Wear Technology”, Dr. Russell Hall, et al, illustrated the variation of wear factor vs. mud additive and/or lubricants, pipe protector, etc.

4. Software

Based on the R & D results from the past two decades, PVI developed CWPRO, a software that enables us to understand the casing wear phenomenon and accurately predict casing wear before the drilling operation or perform post-drilling analysis.

CWPRO is a comprehensive casing wear prediction software with built-in torque and drag function. For every incremental drilling interval, the amount of energy transferred from drill pipe to casing is calculated. Accumulative wear and wear depth are obtained and then, the burst and collapse strength of the worn casing can be assessed.

Being a time-dependent incident, casing wear deepens as we drill deeper. Figure 5 shows the sequence of drilling and corresponding wear profile along the previously set casing.

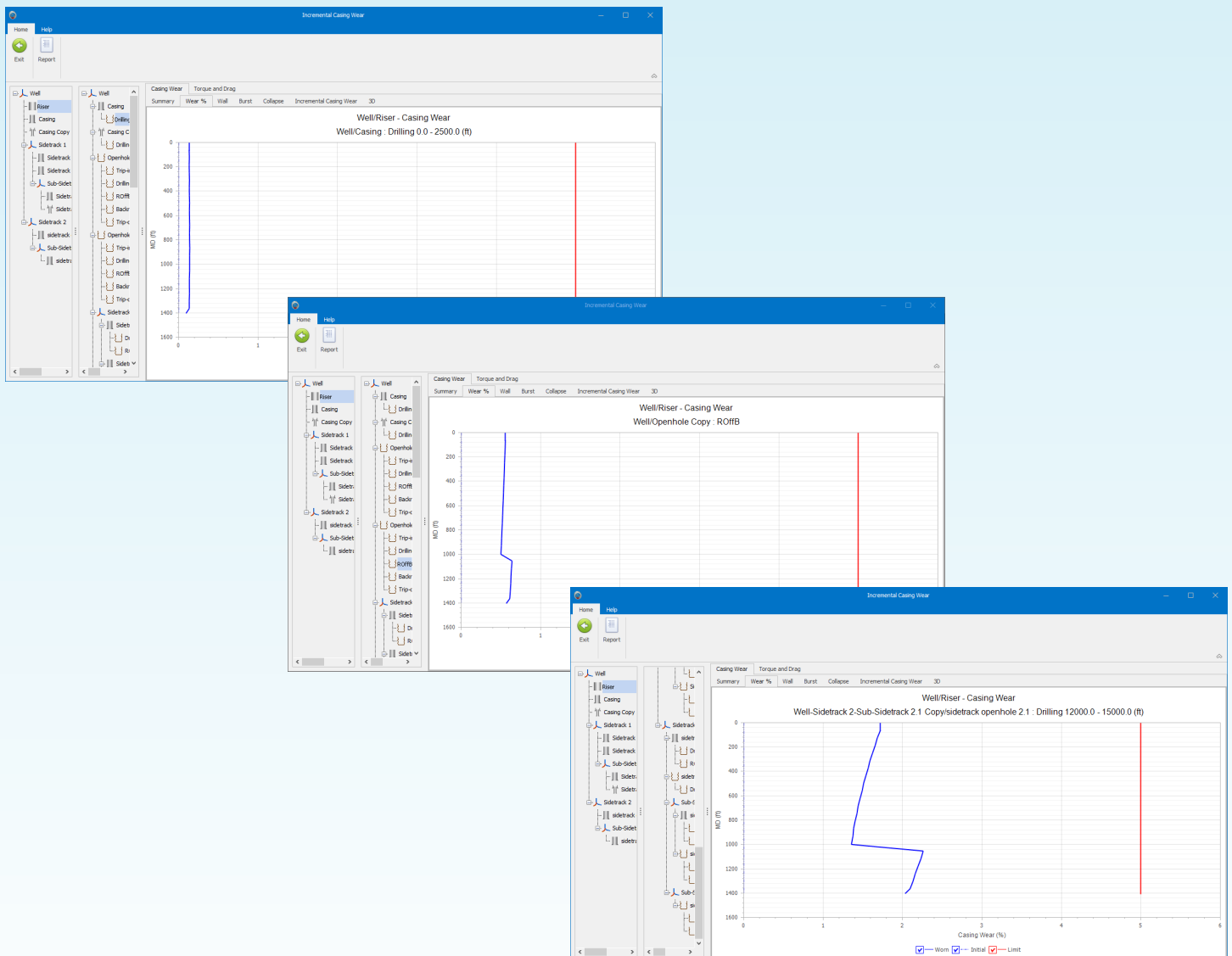


Figure 5. Time-dependent Casing Wear

Figure 6 shows the 3D visualization of the magnitude and the location of the wear in a previously set casing.

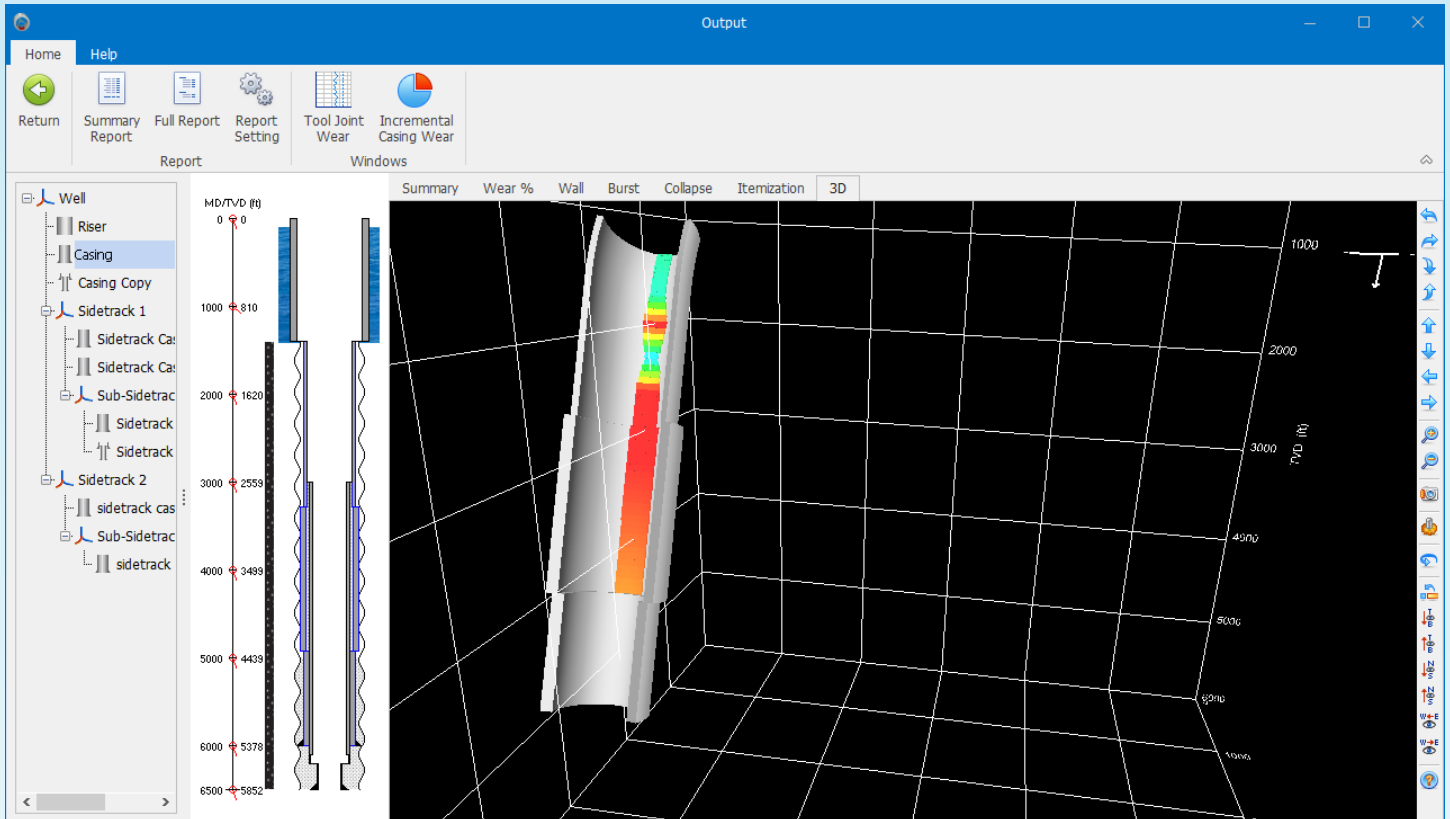


Figure 6. 3D Visualization of Casing Wear

Computer casing wear modeling reduces risks and can identify potential problems prior to its occurring. Necessary modifications on casing designs and drilling parameters could be made before the pumping starts.

III. Case Study

A casing wear study was performed in 3 extended reach wells listed in Table 1. Casing metal shaving was collected during the drilling process, so that computer modeling could be compared with the field measurement.

	Well 1	Well 2	Well 3
Previous Casing	9-5/8", 43.5 lb/ft N-80	9-5/8", 43.5 lb/ft N-80	7", 26 lb/ft K-55 (liner)
Casing Shoe	7,100 ft	8,100 ft	8,500 ft
Shoe Inclination	75°	79°	87°
Open Hole Size	8-1/2"	8-1/2"	6-1/8"
Open Section	8,500 ft	7,500 ft	7,600 ft
TD	15,600 ft	15,600 ft	16,100 ft
Kickoff Point	3,000 ft	3,500 ft	4,000 ft
Drill Pipe	5" DP, 21.93 lb/ft	5" DP, 21.93 lb/ft	4" DP, 16.8 lb/ft
	5" HWDP, 49.262 lb/ft	5" HWDP, 49.262 lb/ft	4" HWDP, 29.664 lb/ft
Drilling Interval	9,000 - 10,250 ft	9,000 - 10,250 ft	8,700 - 9,950 ft

Table 1. Well Design Data for 3 ER Wells

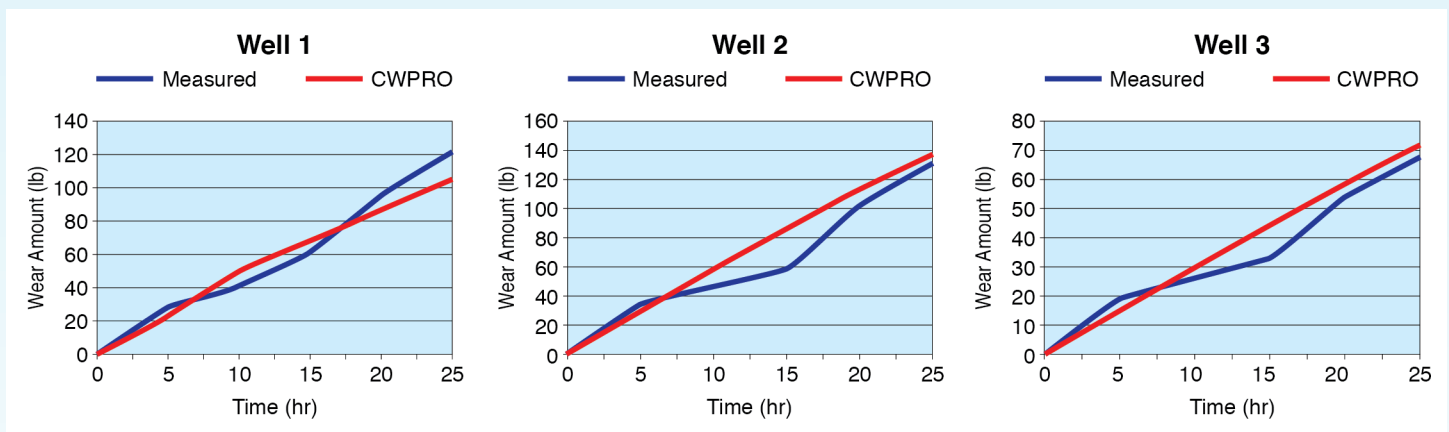


Figure 7. Wear Amount vs. Time

Figure 7. A comparison between the measured weight of the metal shaving versus the calculated casing wear amount using CWPRO (WF: 9, friction factor: 0.25 in cased hole and 0.35 in open hole).

Reasonable agreement or similar trend is observed in the comparison. This shows that software modeling could be very useful in predicting the magnitude and locations of casing wear.

IV. Prevention and Conclusion

The knowledge we have acquired through decades of studies, lab testing, post-job analyses and computer modeling provides a good foundation for the following casing wear preventive measures:

- Minimize dogleg severity and expect real dogleg at least 1.5 times higher than the planned value
- Use casing friendly tool joint materials
- Reduce rotor speed and use downhole motor
- Increase ROP
- Select proper mud type and add lubricants to reduce wear and friction
- Use drill pipe protectors
- Use thick wall casing in the anticipated wear section area
- Use software to reduce risks

V. References

1. Johancsik, C.A, Dawson, R. “Torque and Drag in Directional wells – Prediction and Measurement”, JPT, June, 1984
2. Russell W. Hall Jr., Ali Garkasi, Greg Deskins, and John Vozniak, “Recent Advances in Casing Wear Technology”, IADC/SPE 27532, IADC/SPE Drilling Conference, Feb. 1994
3. G.T. Poss and Russell W. Hall Jr., “Subsea Drilling Riser Wear: A Case History”, SPE/IADC 29392, SPE/IADC Drilling Conference, March 1995.
4. John. G. Mobley, “Hardbanding and Its Role in Directional/Horizontal Drilling”, SPE 52187, March 1999.

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