ADVANCED SUCKER ROD COUPLING MATERIAL OPTIMIZES EFFICIENCY AND PRODUCTIVITY ON ROD LIFT WELLS

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ABSTRACT/SUMMARY

Tubing leaks have historically accounted for nearly half of the failures in the Hess Bakken wells. The root cause of these leaks is coupling on tubing wear. This wear occurs when the non-metallic guides wear out and the spray metal couplings make direct contact with the production tubing. To address this problem, the company installed ToughMet® 3 TS95 sucker rod couplings in over 650 wells, reducing the failure rate in the field. Data analytics were used to analyze the mean time between failures (MTBF) over the last four years.

Several operators are also running entire sucker rod strings with the ToughMet couplings to determine if friction can be reduced and production improved. The results of these pilots are promising. Wells with full strings of ToughMet couplings can see increased fluid production, increased pump fillage, higher fluid loads, and lower gearbox loads.

INTRODUCTION

Sucker rod pumping of 10,000 ft. unconventional wells presents challenges related to deviation and side loading of rods. When rods flex during the down stroke of the pumping unit, sucker rod couplings wear into the inner wall of the production tubing. Well failures attributed to excessive coupling and tubing wear result in significant workover costs and deferred production. In Hess North Dakota Bakken properties, half of all failures occur in the well's bottom 1,000 ft. The primary culprit of production tubing wear in this area is spray metal couplings. These couplings tend to wear away the tubing to the point of failure because the nickel-chrome coating is much harder and more abrasive than L-80 steel tubing.

While standard T couplings are not as hard as spray metal couplings, they still result in tubing wear by a steel-on-steel galling mechanism. Metals gall due to atomic welding at the contacting surfaces. No surface is perfectly smooth and all metals have microscopic peaks and valleys called asperities. When two surfaces come in contact under a load, the asperities experience a large amount of local pressure and form a microweld bond which results in metal transfer. Since metals generally weld best to themselves, two steel alloys sliding against each other will tend to gall under heavy loads. As a low friction copper alloy, ToughMet 3 TS95 is dissimilar and naturally anti-galling to steel production tubing.

Beginning in 2014, Hess addressed tubing leaks by implementing ToughMet 3 TS95 couplings in highly deviated sections of wells. This high strength spinodal CuNiSn alloy was designed for bearing applications and was an ideal match for sucker rod couplings because it resists contact abrasion in sliding applications. ToughMet 3 TS95 has a similar hardness to L-80 steel (HRC 21 vs. HRC 23) and is compatible with the production tubing due to its low friction when sliding against steels. The alloy also offers improved corrosion resistance over other bronze alloys because it contains 15% Ni and 8% Sn.

Because of the alloy's low friction properties, there are additional benefits operators can capture besides reduced tubing wear. Operators hypothesized that decreased friction on the well might increase production, stroke length and pump fillage as well as decrease pump friction, polished rod loads, and gearbox loads. Materion is working with Hess and other operators in the Bakken and Permian to quantify these effects.

PHASE 1: PILOT & EXPANSION

In Phase 1 of the program, Hess replaced spray metal couplings with ToughMet couplings in troublesome wells with deep tubing leaks. Originally, ten pilot wells were selected to trial 25 to 60 of the new ToughMet couplings. These pilot wells achieved runtimes from 700 to over 1,000 days after the installation of the new couplings, representing a service runtime of 9.365 million cyclic stress cycles. For the initial trial wells running at 6 strokes per minute (SPM), the MTBF increased from 6 to 12 months to 18 to 30 months.

Hess has since installed ToughMet sucker rod couplings into more than 650 wells in the Bakken to combat tubing leaks in problematic sections of the well. Most wells received 12 to 40 ToughMet couplings depending on the locations of frequent tubing leaks. Since implementation in 2014, no coupling failures have been observed due to wear, corrosion, or fatigue.

Data analytics have been used to assess current and historical time before failure in 42 wells running ToughMet couplings. Rod, pump, and other failures were excluded from this analysis, so only wells with a history of tubing leaks were included in the data set. Figure 1 in the Appendix shows current tubing run time of wells running with ToughMet couplings vs. each well's historical mean tubing run time. The diagonal reference line represents a break-even point at which the current tubing run time equals the mean time to failure prior to ToughMet coupling installation. As of the end of February 2018, the current run times of these 42 wells running ToughMet couplings are largely above this reference line, indicating an improvement in run time over mean time to failure before the new couplings were implemented.

It important to emphasize that the data points representing current run times vs. mean tubing run time before ToughMet coupling installation will only improve over time. As the wells continue to run, the data points will rise over the diagonal break-even point. At this time, 32 of the wells in this data set have outperformed their historical mean run time before tubing failure. For these 32 wells, the average tubing run time before failure for these wells was 353 days prior to ToughMet coupling installation. The current run time average is 567 days. This corresponds to a 61% improvement in tubing failure run time.

In the following months, a larger data set of over 200 wells will be analyzed with similar methods. Historical time before tubing failure will be compared to current and median post-ToughMet coupling run times. To do this, the tubing failure data will be filtered by location in the wellbore. Therefore, the calculated median tubing run times will exclude tubing leaks that occurred in sections where ToughMet couplings were not present to ensure an accurate depiction of increased run time.

PHASE 2: TOUGHMET COUPLING FULL STRING FIELD TRIALS

In Phase 2 of the ToughMet coupling program, Hess and other operators are testing the hypothesis that running entire sucker rod strings or larger sections of ToughMet couplings reduces overall friction in the well. Lower friction would enable increased net stroke length and therefore, increase production an estimated 6 to 20% in each well. Currently, 7 wells between the Bakken and Permian are running full strings of ToughMet couplings. By the end of June 2018, 26 additional wells will be added, totaling 33 wells running entire sucker rod strings of ToughMet couplings. Seven of these additional wells have been confirmed for installation by the end of March 2018. Each participating operator has individually selected the candidate well for the ToughMet coupling full string field trial. Most of the wells were previously on rod lift so current production, friction, and load data have been compared to historical metrics. In these wells, operators did not change the bottomhole assembly configurations and maintained the same rod string design.

Initial data has been obtained from one Hess well and two Permian wells running full strings of ToughMet couplings. Additional results were considered from two Permian wells running larger sections of ToughMet couplings. Table 1 summarizes the Phase 2 case studies that are discussed in the following sections.

Table 1- Wells Running Full Sucker Rod Strings or Large Sections of ToughMet Couplings

E&P	Shale Play	Well	Install Date	# Couplings	Pump Size	Run Time Since Install (months)
Hess	Bakken	H4	11/5/17	435	2”	4
X	Permian	Full String A	8/3/17	186	1.75”	7
Y	Permian	Full String B	1/30/17	456	1.25”	1
X	Permian	Partial String A	8/22/17	126	2”	6.5
X	Permian	Partial String B	7/12/17	64	1.75”	8

Hess Full String Field Trial: H4

An entire sucker rod string of ToughMet couplings was installed in November 2017 into horizontal well H4. Prior to this, the H4 well was flowing independently, so the 435 ToughMet couplings were implemented upon initial artificial lift install. Thus, the current data is being compared to H5, which is an offset sister well on the same drilling pad. H5 is running spray metal couplings and was selected for comparison because it has similar wellbore tortuosity and is running the same sized pump as the H4 well. However, it is noteworthy that H4 and H5 wells are pumping from the Middle Bakken and Three Forks formation, respectively. This is an added challenge in determining the frictional benefits that the ToughMet couplings have on the rod string because the fluid properties of the two formations may differ. Both H4 and H5 are running rod rotators, guides, steel rods, and L80 production tubing. Refer to Table 2 for general well details of each.

Table 2- Well Details of H4 and H5

	H4	H5
Well Type	Horizontal	Horizontal
Pump Size	2”	2”
Formation	Middle Bakken	Three Forks
Pump Set Depth	9800 ft	9850 ft
Rods	Steel	Steel
Production Tubing	L80	L80
Rod Guides	Yes	Yes
Rod Rotators	Yes	Yes
SPM	6.2	6.2
Avg/Max Side Load	60/335 lbs	40/130 lbs

Figures 2 and 3 in the Appendix display the production trends of the H4 and H5 wells after 80 days of run time. Since artificial lift install, H4 averaged 274 bpd of oil, 676 mscf of gas per day, and 54 bpd of water. In comparison, the spray metal well averaged 197 bpd of oil, 163 mscf of gas per day, and 102 bpd of water over its first 80 days after initial artificial lift install. Although it is difficult to compare production trends from two different wells, the well running the ToughMet full string did not show an extreme drop off in production upon artificial lift install as would normally occur. Also, the H4 well is producing much more consistently than the H5 well, as shown in Figure 4 in the Appendix.

Improvements in H4’s pump friction, pump fillage, net stroke length, gear box loads, and polished rod loads cannot be concluded at this time. The operator has stated that the H4 well has not fully stabilized as fluid continues to flow up the well’s casing. Because the well was not running on artificial lift before ToughMet coupling installation, the friction in the well may not stabilize for several more months. Despite this, the peak polished rod loads in the ToughMet well seem to be more consistent over the first 60 days than the H5 sister well, as shown in Figure 5 in the Appendix. In the ToughMet coupling full string well, the mean polished rod peak load was 30623 lbs. with a standard deviation of 554 lbs. In the spray metal well, the mean peak load was 32363 lbs. with a standard deviation of 1215 over the same time period. In addition to showing a 5% decrease, the peak polished rod load data is more consistent in the ToughMet full string well than the sister well running spray metal couplings, as indicated by a 54% smaller standard deviation for the mean peak load.

Permian Operator X: Full String Well A

A Permian operator installed an entire sucker rod string of consisting of 186 ToughMet couplings into a horizontal well in August 2017. This well ran on rod pump with both SM and T couplings prior to the

ToughMet couplings. Historically it had failed every 6 to10 months due to a tubing leak or rod failure. Upon workover, the same 1.75” pump was rebuilt and reinstalled and fiber glass rods, tubing rotators, rod rotators, and rod guides were maintained. Half of the L80 production tubing was also replaced upon workover. The pump set depth was 6656 ft. and side loads average 240 lbs. The designed stroke length was 130” and the well is running at 7 SPM on a variable speed drive. Since ToughMet coupling were installed, this well has been running for 7 months and counting.

Table 3 shows the oil, gas, and water production averages of the well running 186 ToughMet couplings over the past five months compared to the averages prior to ToughMet couplings. Mean oil production has averaged 19% greater and has been trending upwards. Most recently, oil production was over 150% greater than its historical average. Table 3 also shows stroke length, pump fillage, gear box loads, polished rod loads, and fluid level. When the operator was running the well with spray metal and T couplings, the well showed 132” stroke length vs. a 130” designed stroked length. After the full string of ToughMet couplings was installed, the net stroke length was between 150” and 155”, gaining 18” to 23” of extra stroke length compared to its pre-ToughMet average. This indicates that the ToughMet couplings are reducing friction in the well, allowing the rod string to capture more net stroke length. Pump fillage is between 92 and 99.85% compared to an average of 90% when the well was running spray metal and T couplings before. Likewise, loads on the well’s gear box as a percentage of its designed max load decreased from 84% to between 59 and 64%, suggesting possible decreased power usage and potential increased gear box life. Lastly, the polished rod load is trending upward but still remains significantly below the historical average.

Table 3- Performance Metrics of Permian Full String Well A Running 186 ToughMet Couplings

	Before ToughMet	After ToughMet	Change	% Change
Oil (bpd)	110	130.5	20.5	19%
Gas (mscfpd)	186	144.25	-41.75	-22%
Water (bpd)	124	126.75	2.75	2%
Stroke Length (in)	132.0	153.3	21.3	16%
Fluid Level Above Pump (ft)	1590	1096	-494	-31%
Pump Fillage	90%	95%	5%	6%
Gear Box Load vs. Design Max	84%	62%	-22%	-27%
Peak Polished Rod Loads	22302	19174	-3128	-14%

Permian Operator Y: Full String Well B

Another Permian operator installed an entire sucker rod string of 456 ToughMet couplings into a vertical 11411 ft. well in January 2018. This is a lower producing well that previously ran spray metal and T couplings. Historically, its failure frequency was an average 119 days due to various failure modes. Upon workover, the same 1.25” pump was reinstalled and no tubing rotators, rod rotators, or rod guides were implemented; the same well design was maintained before and after. Refer to Table 4 for the well details.

Table 4- Details Full String Well B Running 456 ToughMet Couplings

	Full String Well B
# ToughMet Couplings	456
Pump Set Depth	11411
Pump Size	1.25”
Production Tubing	N80
Rods	Norris 90 Steel
SPM	7.1 (VSD)
Designed Stroke Length	100”
Side Loads	50-90 lbs
Guides	No
Rod/Tubing Rotators	No

Early data gathered after a month of run time suggests that the ToughMet couplings may be significantly reducing friction in this well as indicated by reduced gear box loads and increased production, effective

net stroke length, and pump fillage. Table 5 summarizes these results. Before ToughMet couplings were installed, gear box loading was 87%, but loading was reduced to 77% after 31 days of running ToughMet couplings. The oil production rate increased from 19 bpd to 22 bpd (16% increase), effective net stroke increased from 69.6 to 80 inches (15% increase), and pump fillage increased from 80% to 100%. Averages over a longer period of time will be gathered as the well continues to run.

Table 5- Performance Metrics of Permian Full String Well B Before and After ToughMet Coupling Installation

	Before ToughMet	After ToughMet	Change	% Change
Oil (bbl)	19	22	3	16%
Water (bbl)	53	49	-4	-8%
Gas (mscf/day)	119	118	-1	-1%
Gearbox Loading %	87	77	-10	-11%
SPM	7.4	7.6	0.2	3%
Effective Net Stroke (in)	69.6	80	10.4	15%
Pump Fillage %	80	100	20	25%
Pump Vol. Efficiency %	55	64	9	16%
Peak Polished Rod Load (lbs)	27464	26839	-625	-2%
Min Polished Rod Load (lbs)	15728	16143	415	3%
Fluid Level Above Pump (ft)	2527	1905	-622	-25%

Permian Operator X: Partial Wells A & B

Two wells operating in the Permian are running large sections of ToughMet couplings and capturing the expected benefits of reduced friction. Both wells were running on rod pump prior to ToughMet coupling installation and were using spray metal couplings. New L80 production tubing was installed in both wells. Upon workover, no major design changes were made to Partial Well A. In Partial Well B, tubing rotators were not reinstalled. Refer to Table 6 for the well details of these partial string field trials.

Table 6- Details of Permian Wells Running Large Sections of ToughMet Couplings

	Partial Well A	Partial Well B
# ToughMet Couplings	126	64
Pump Set Depth	8880 ft	9096 ft
Pump Size	2”	1.75”
Tubing	L80	L80
Rods	Fiberglass/Steel	Fiberglass/Steel
SPM	7.5 (VSD)	6.58 – 7.5 (VSD)
Designed Stroke Length	109”	110”
Side Loads	515 lbs	380 lbs
Dog Leg Severity	3.48	2.41
Guides	Yes	Yes

Data gathered over the past 6.5 to 8 months, shows that Partial Well A and B both experienced increased production, increased stroke length, and decreased gear box loading by running 126 and 64 ToughMet couplings, respectively. These results are summarized in Tables 7 and 8.

In Partial Well A, oil production increased an average of 49 bpd (44%), stroke length increased by an average of 52.5 inches (42%), and average polished rod loads decreased by 9000 lbs (28%). Gear box loading was designed to be at 76.5% of its suggested max load and averaged 74.6% with the spray metal couplings. After ToughMet couplings were installed, the average gear box load averaged 63%, which is 11.9% below the spray metal average or 13.8% below the designed target.

As shown in Table 8, Partial Well B showed a 3% increase in oil production (3.5 bpd), a 46% increase in stroke length (51 inches), and an 18% improvement in pump fillage to an average of 94%. Loads on surface equipment also improved, as gear box loads decreased from 70% to an average of 63.5% and peak polished rod loads decreased by about 4400 lbs. The post-ToughMet coupling averages represent a 9.3% and 15% improvement in gear box and polished rod loads, respectively.

Also noteworthy is that Partial Well A ran twice as many ToughMet couplings as Partial Well B and experienced significantly greater reduction to gear box and polished rod loads. This suggests that overall well friction and loads on surface equipment can be decreased further by installing ToughMet couplings in a larger portion of the sucker rod string.

Table 7- Permian Partial String Well A Performance Metrics Before and After ToughMet Coupling Installation

	Before ToughMet	After ToughMet	Change	% Change
Oil (bpd)	111	160	49	44%
Gas (mscfpd)	220	244	24	11%
Water (bpd)	104	242	138	132%
Stroke Length (in)	126.4	179	53	42%
Fluid Level Above Pump (ft)	1629	1595	-34	-2%
Pump Fillage	99.00%	98.97%	-0.03%	-0.03%
Gear Box Load vs. Design Max	74.6%	62.7%	-11.9%	-15.9%
Peak Polished Rod Load (lbs)	31893	23011	-8882	-28%

Table 8- Permian Partial String Well B Performance Metrics Before and After ToughMet Coupling Installation

	Before ToughMet	After ToughMet	Change	% Change
Oil (bpd)	128	131.5	3.5	3%
Gas (mscfpd)	84	102	18	21%
Water (bpd)	434	351	-83	-19%
Stroke Length (in)	110	161	51	46%
Fluid Level Above Pump (ft)	4665	1605	-3060	-66%
Pump Fillage	80%	94%	14%	18%
Gear Box Load vs. Design Max	70.0%	63.5%	-6.5%	-9.3%
Peak Polished Rod Loads (lbs)	28728	24336	-4393	-15%
Pumping Unit Loading	79%	76%	-3%	-4%

SUMMARY AND CONCLUSIONS

The following observations were made about the use of ToughMet 3 TS95 sucker rod couplings:

Over 650 Hess wells in the Bakken now have ToughMet couplings in the bottom section of the sucker rod string. In these wells:

- Tubing wear has been reduced
- Current run times of wells running ToughMet couplings are exceeding historical mean time before tubing failure
- No ToughMet coupling failures have been observed

Based on 3 wells running full strings of ToughMet couplings and 2 wells running large sections of ToughMet couplings, data suggests that running this coupling has a measureable effect due to decreased friction. The following observations have been made about the field trials discussed in this paper:

- Oil production can be increased between 3 and 44%
- Oil production levels can be stabilized and more consistent
- Net stroke length can be increased between 15 and 46%
- Polished rod loading can be decreased between 2 and 28%
- Gear box loading can be decreased between 9 and 27%
- Pump fillage can be increased between 6 and 25%
- Life of surface equipment can be increased due to decreased loading

The initial data shows promising results about the role of the couplings in reducing friction on the rod string. Data will continued to be gathered as the 7 current ToughMet coupling full string field trials run and an additional 26 full string field trial wells are installed. Wells selected as candidates for the future full string field trials will be selected on the basis that they are consistent producers on rod lift. This way, the

benefits of running full sucker rod strings or larger sections of ToughMet couplings can be more easily quantified. If the early data is representative of the frictional benefits ToughMet couplings provide, operators will likely see significantly reduced HIT failures, production increases, and reduced loads on surface equipment by running large sections of these couplings.

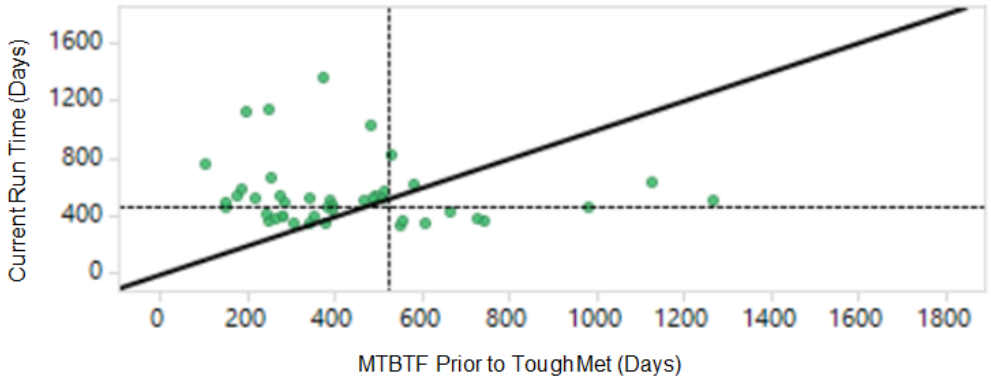

Figure 1: Current Tubing run times of 42 wells running ToughMet sucker rod couplings compared to historical MTBTF

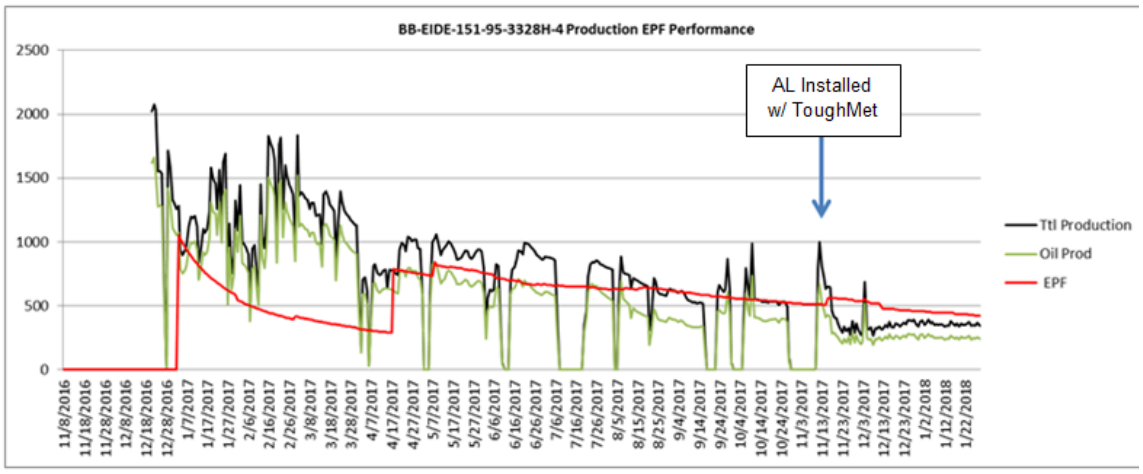

Figure 2: H4 production trends before and after artificial lift install

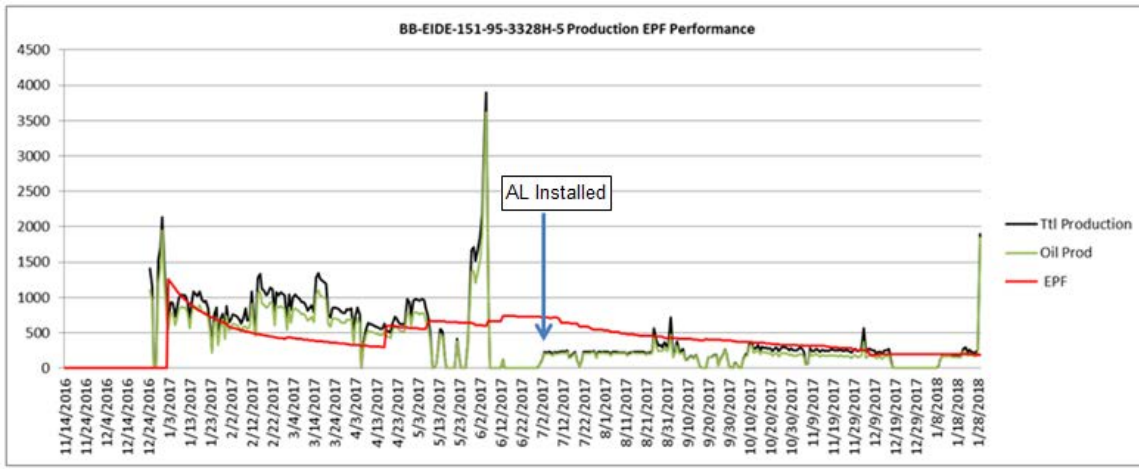

Figure 3: H5 production trends before and after artificial lift install

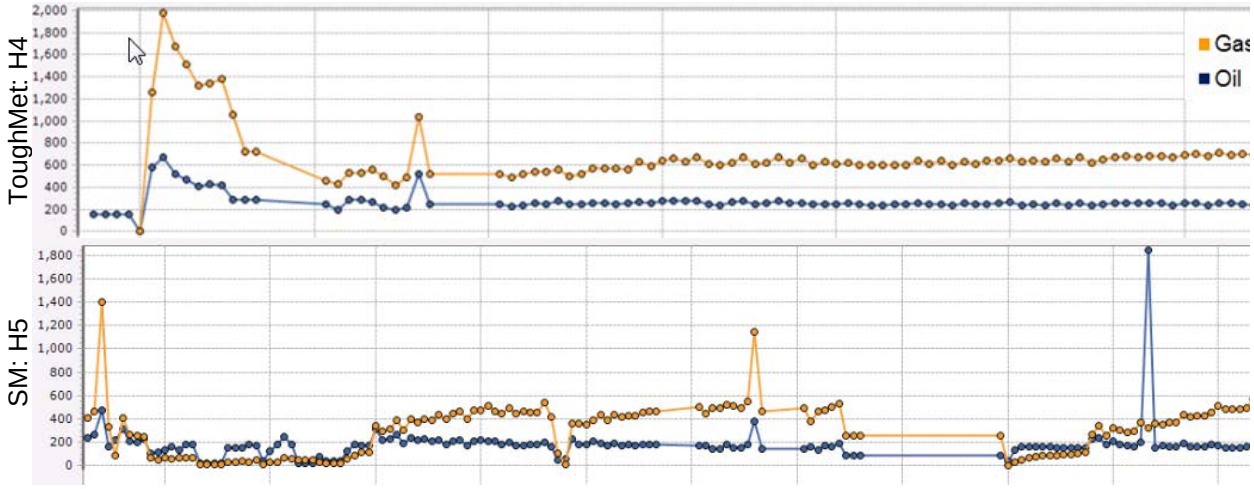

Figure 4: Oil and gas production of H4 and H5 since ToughMet coupling installation – 105 days

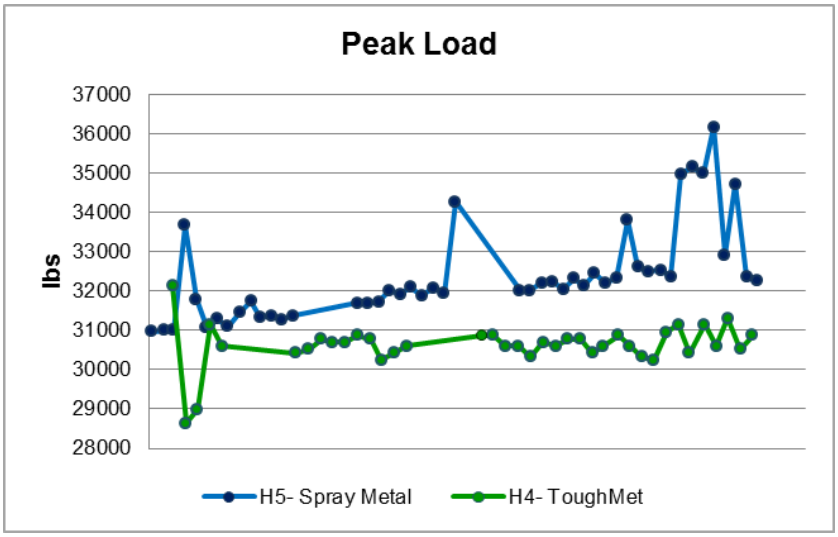

Figure 5: Average peak load comparison of Hess well H4 running a full string of ToughMet couplings compared to a sister well running spray metal couplings – 60 days