Boron-Carbide Treated Couplings Improve Rod Lift Efficiency in South Texas Wells

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LANDSCAPE

- Rod lift is one of the most prevalent forms of artificial lift
  - Over 150 years of usage – has withstood the test of time
  - Continuously evolving to meet the needs of a changing industry

- Current production environment is challenging
  - Sand
  - Corrosion
  - Highly deviated well-bores

  →

  - Excessive wear
  - More frequent wellbore interventions required
  - Increased downtime

- Solutions to these challenges are continuing to be developed and implemented
  - System design and optimization
  - Technology developments
  - Others…

FIELD STUDY - ASSESSING NEW TECHNOLOGY

OBJECTIVES

- Explore the benefits of boron-carbide (B_4C) treated steel couplings in addressing mechanical wear and abrasion in sucker rod pump (SRP) wells.

- The primary goal (benefit desired) = reduce rod-on-tubing wear. However, it is still too early to conclude this objective is being met --- more run time required.

- The secondary benefits, further explored >>> increased lifting efficiency, improved production, and decreased peak polish rod loads (PPL).
  - Each of these benefits would be attributed to the reduced friction coefficient of B_4C treated couplings.

EVALUATION

- Sample of twenty sucker rod pump (SRP) wells.
- Assess benefits of using low friction B_4C couplings in the sucker rod string.
- Select wells with greater than fifty B_4C couplings installed within the rod string design.
- Compare data elements before and after installation of the B_4C couplings such as:
  - Peak polished rod load
  - Net load
  - Gross stroke change
  - Fluid production

PARAMETERS

- All of wells historically had mechanical wear and abrasion issues due to sand, side load, and friction within the rod string.
- The well depths in this study averaged 8,792 feet and ranged from 6,975 feet to 10,450 feet total depth.
- Pump sizes were between 1.25” O.D. to 2.00” O.D., which remained constant for the before and after assessment (i.e., no pump sizes were changed).
- To reduce the noise of varying wellbore conditions - only days that had oil production greater than 60% of its respective forecast were considered in the analysis.
- Well data was pulled and compared various metrics before and after installation of the B_4C couplings.

Field Practices

- Chesapeake utilizes B_4C couplings in rod string sections that have **greater than two hundred pounds of side load** modeled before rod string installation. These higher side load areas tend to show greater coupling and tubing wear due to higher friction and abrasive wear over time.
- Additionally, B_4C couplings are located in the string in areas where abnormal coupling wear is identified when pulling rod strings out of hole during a workover event.

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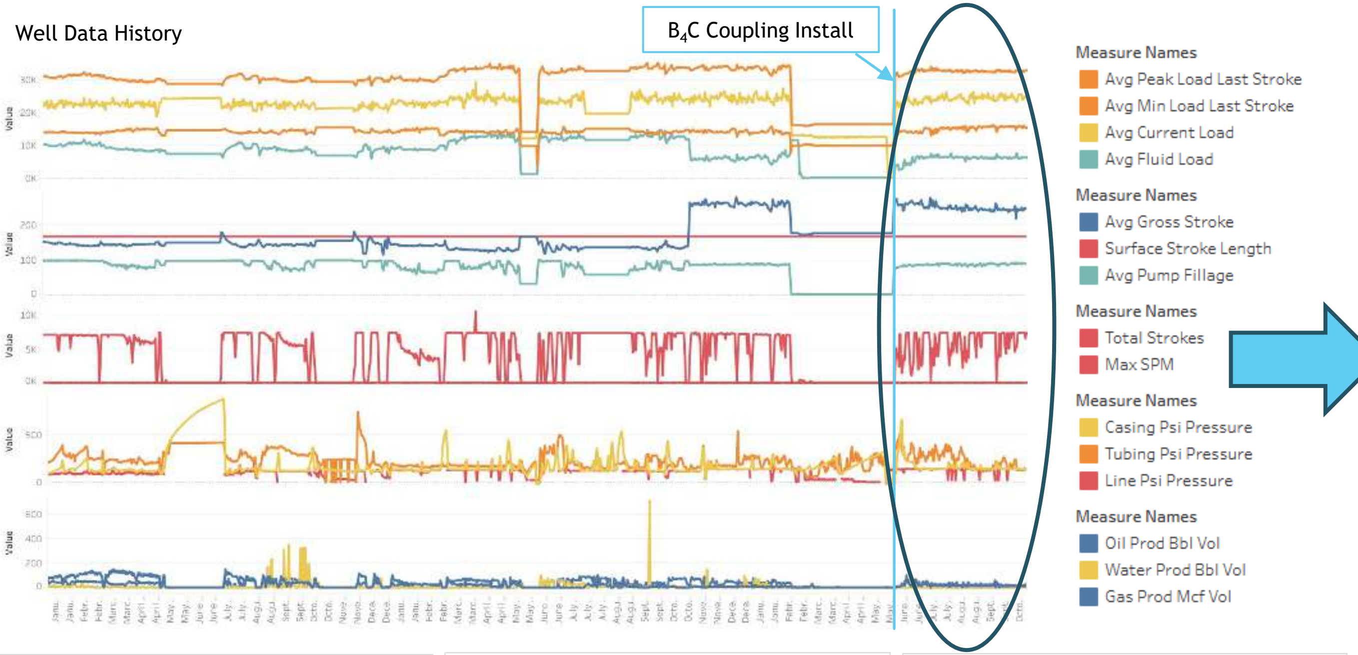
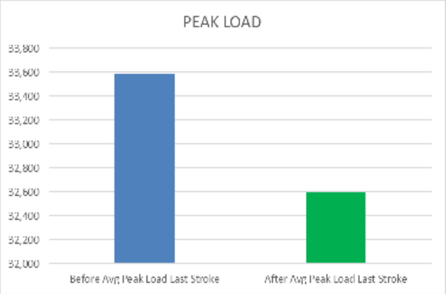
WELL "E" – high usage example

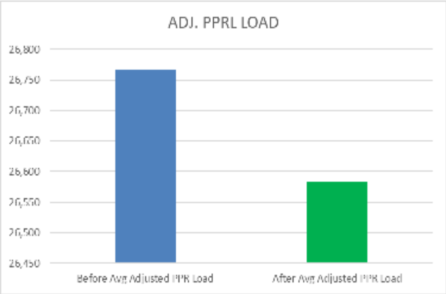
Parameter	Value
# of B_4C Couplings	149
Avg. Side Load (lbs.) / Max Side Load (lbs.)	147 / 187
Prior Failure Modes	Parted Rod/Coupling, Rod/tubing Wear
Run Time Days - Evaluation Horizon	143
Total Install Days - (as of 7.31.2023)	430

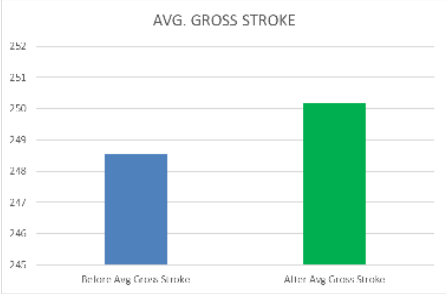


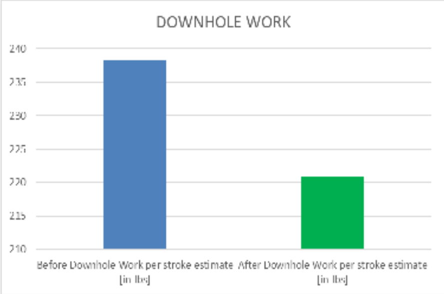
Before/After Assessment - >60% of Oil Production Forecast

	BEFORE	AFTER
Pump SZ	1.50	1.50
Coupling QTY	n/a	149
Avg Peak Load	**33,585**	**32,604**
Avg Min Load	14,096	15,088
Delta PL - ML	19,489	17,516
Avg Current Load	24,330	24,249
Avg Fluid Load	6,818	6,021
Avg Adjusted PPR Load	**26,767**	**26,583**
Avg Gross Stoke	249	250
Avg Surface Stroke	169	169
Avg Net Stroke	218	218
Delta SS -GS	(80)	(82)
Avg Pump Fillage	88	88
Avg SPM (Cygnet Spot Avg)	5	5
Oil Prod	10	19
Fluid Production / 1000 strokes	3	3
Downhole Work per stroke estimate [in-lbs]	238	221
Adj Peak Polished Rod Work	4.26	8.06
Calc Data		
PPRL CHANGE		(980)
APPRL CHANGE		(184)
Change in Downhole Work per stroke[in-lbs]		-17
Gross Stroke Gain/(Loss)		2
Net Load Delta (neg = good)		(1,176)
% Change in Oil Production		93%





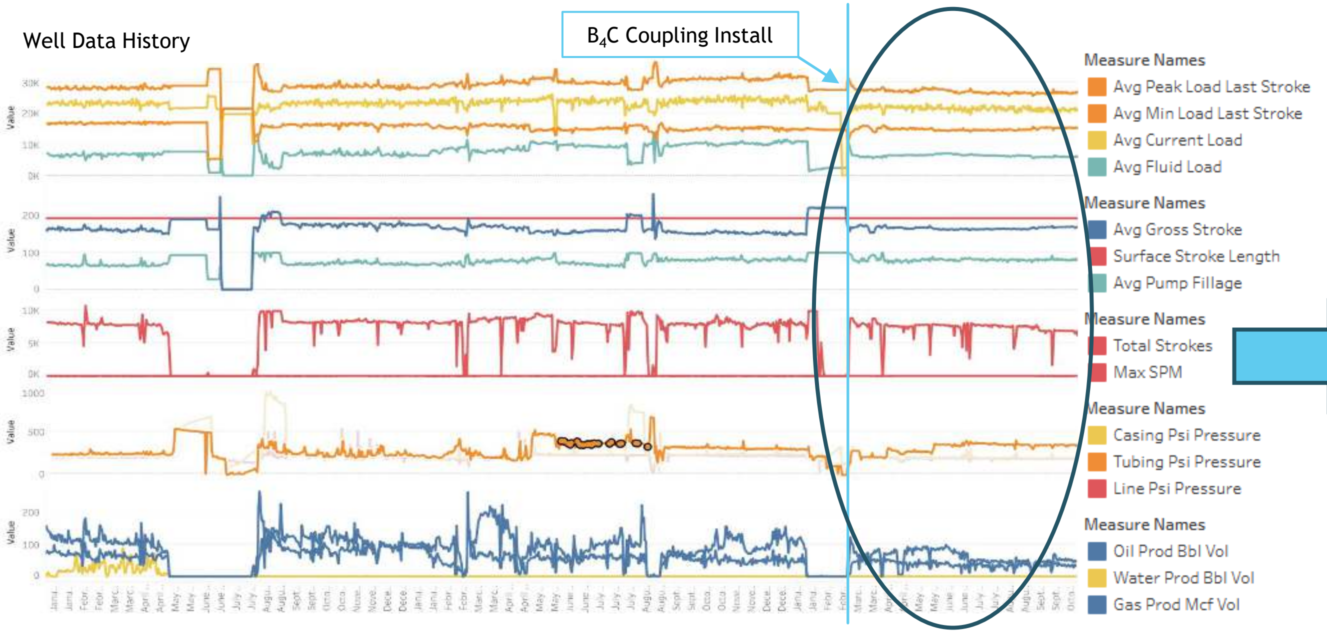




B_4C Couplings lead to reduced peak load, greater gross stroke, less downhole work and improved oil production.

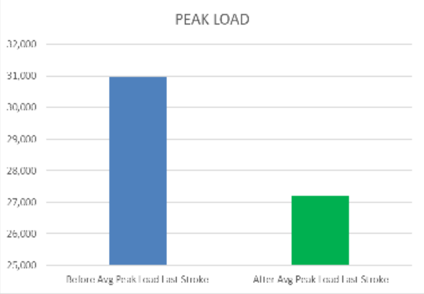
WELL "N" – moderate usage example

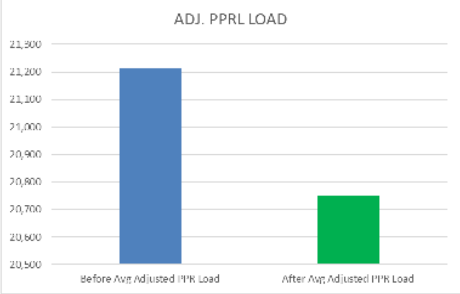
Parameter	Value
# of B_4C Couplings	80
Avg. Side Load (lbs.) / Max Side Load (lbs.)	58 / 72
Prior Failure Modes	Rod/Tubing Wear, Tubing Leak
Run Time Days - Evaluation Horizon	231
Total Install Days - (as of 7.31.2023)	518

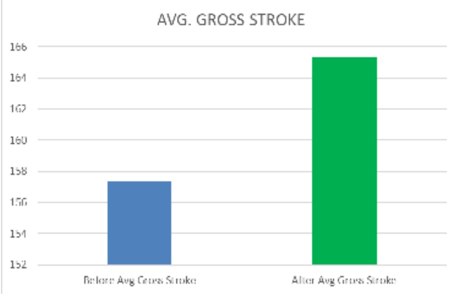


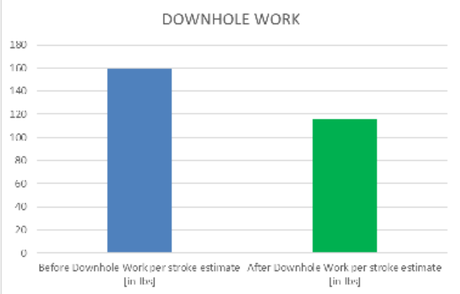
Before/After Assessment - >60% of Oil Production Forecast

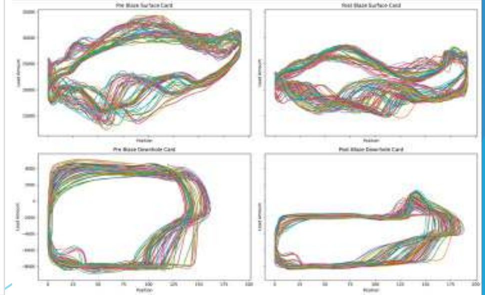
	BEFORE	AFTER
Pump SZ	2.00	2.00
Coupling QTY	n/a	80
Avg Peak Load	**30,957**	**27,206**
Avg Min Load	15,229	14,987
Delta PL - ML	15,728	12,219
Avg Current Load	24,147	21,708
Avg Fluid Load	9,746	6,454
Avg Adjusted PPR Load	**21,211**	**20,753**
Avg Gross Stoke	157	165
Avg Surface Stroke	192	192
Avg Net Stroke	128	128
Delta SS -GS	35	27
Avg Pump Fillage	81	80
Avg SPM (Cygnet Spot Avg)	6	5
Oil Prod	53	42
Fluid Production / 1000 strokes	7	6
Downhole Work per stroke estimate [in-lbs]	159	116
Adj Peak Polished Rod Work	6.40	8.30
Calc Data		
PPRL CHANGE		(3,751)
APPRL CHANGE		(459)
Change in Downhole Work per stroke[in-lbs]		-43
Gross Stroke Gain/(Loss)		8
Net Load Delta (neg = good)		(217)
% Change in Oil Production		-21%







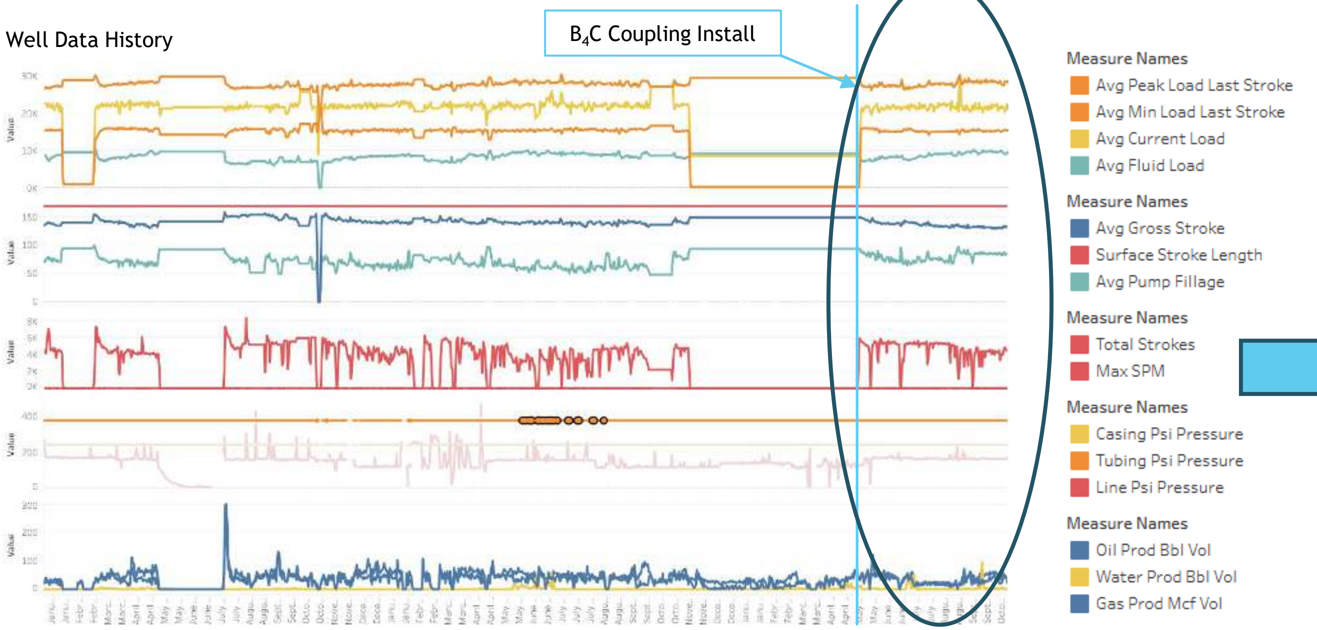




Despite lower fluid production, improved lifting efficiency achieved as reflected in downhole cards.

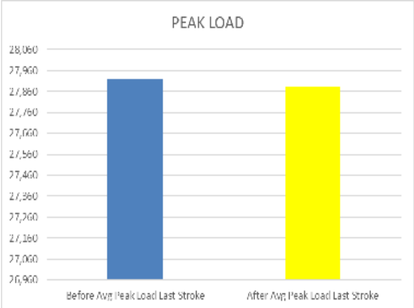
WELL “L - low usage example

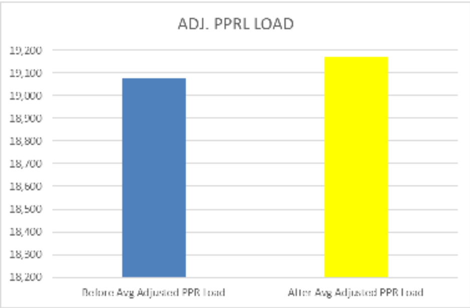
Parameter	Value
# of B_4C Couplings	71
Avg. Side Load (lbs.) / Max Side Load (lbs.)	70 / 136
Prior Failure Modes	HIT, Rod Wear, Coupling Part
Run Time Days - Evaluation Horizon	170
Total Install Days - (as of 7.31.2023)	457

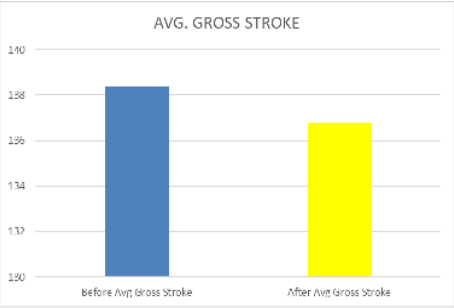


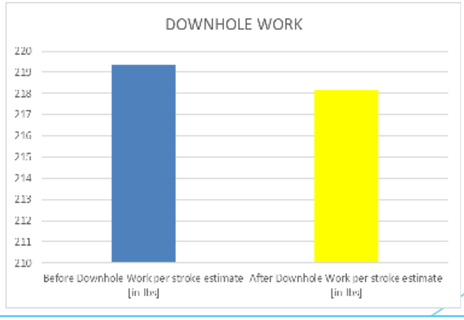
Before/After Assessment - >60% of Oil Production Forecast

	BEFORE	AFTER
Pump SZ	1.50	1.50
Coupling QTY	n/a	71
Avg Peak Load	**27,920**	**27,881**
Avg Min Load	15,500	14,080
Delta PL - ML	12,420	13,800
Avg Current Load	22,751	20,610
Avg Fluid Load	8,841	8,708
Avg Adjusted PPR Load	**19,078**	**19,173**
Avg Gross Stoke	138	137
Avg Surface Stroke	168	168
Avg Net Stroke	85	85
Delta SS -GS	30	31
Avg Pump Fillage	61	80
Avg SPM (Cygnet Spot Avg)	3	4
Oil Prod	35	33
Fluid Production / 1000 strokes	11	8
Downhole Work per stroke estimate [in-lbs]	219	218
Adj Peak Polished Rod Work	1.24	2.11
Calc Data		
PPRL CHANGE		(39)
APPRL CHANGE		94
Change in Downhole Work per stroke[in-lbs]		-1
Gross Stroke Gain/(Loss)		-2
Net Load Delta (neg = good)		1,514
% Change in Oil Production		-8%





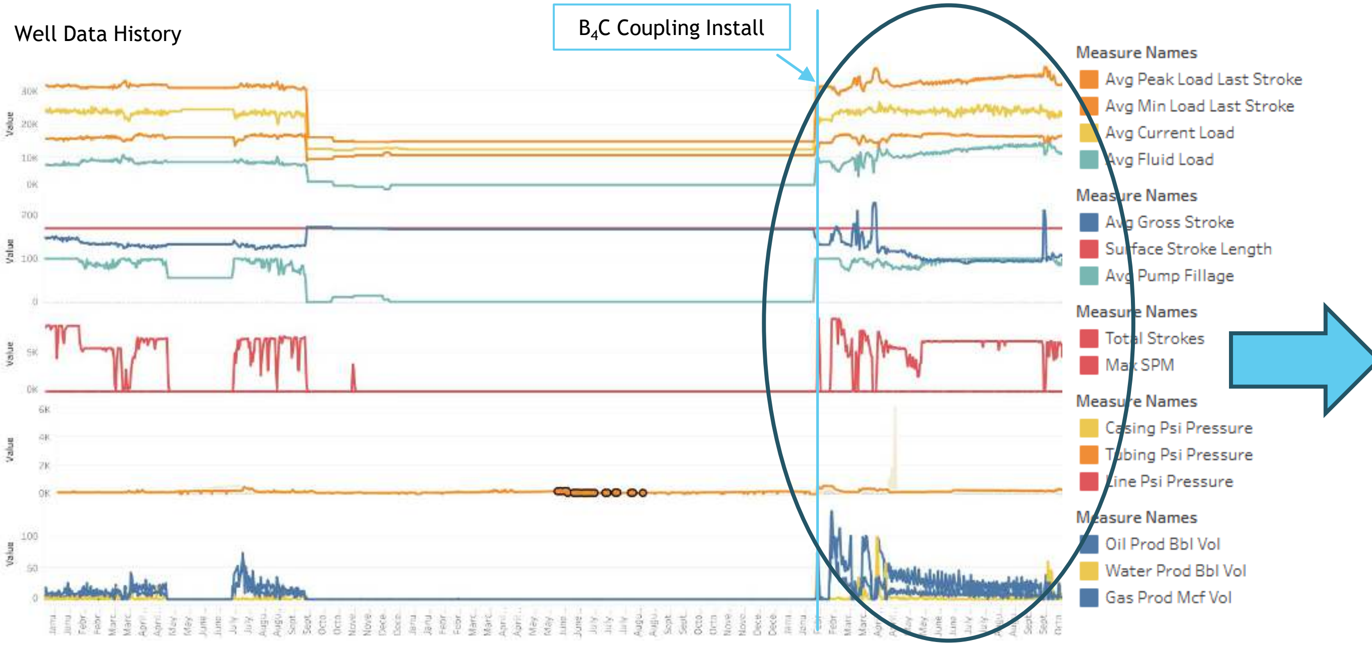




B_4C Couplings used to address failures, nominal ancillary benefits achieved.

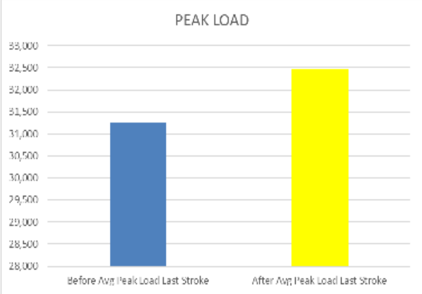
WELL “G – low usage example

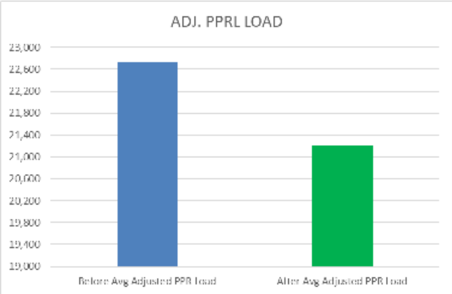
Parameter	Value
# of B_4C Couplings	68
Avg. Side Load (lbs.) / Max Side Load (lbs.)	100 / 100
Prior Failure Modes	Parted Rod/Coupling, Stuck Pump
Run Time Days - Evaluation Horizon	255
Total Install Days - (as of 7.31.2023)	542

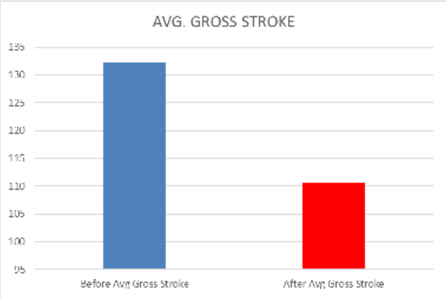


Before/After Assessment - >60% of Oil Production Forecast

	BEFORE	AFTER
Pump SZ	1.25	1.25
Coupling QTY	n/a	68
Avg Peak Load	**31,269**	**32,473**
Avg Min Load	16,110	16,303
Delta PL - ML	15,159	16,169
Avg Current Load	23,365	23,771
Avg Fluid Load	8,540	11,259
Avg Adjusted PPR Load	**22,729**	**21,214**
Avg Gross Stoke	132	111
Avg Surface Stroke	169	169
Avg Net Stroke	114	114
Delta SS -GS	37	59
Avg Pump Fillage	91	93
Avg SPM (Cygnet Spot Avg)	5	5
Oil Prod	14	17
Fluid Production / 1000 strokes	3	3
Downhole Work per stroke estimate [in-lbs]	160	173
Adj Peak Polished Rod Work	11.03	9.29
Calc Data		
PPRL CHANGE		1,204
APPRL CHANGE		(1,514)
Change in Downhole Work per stroke[in-lbs]		13
Gross Stroke Gain/(Loss)		-22
Net Load Delta (neg = good)		(1,708)
% Change in Oil Production		23%







B_4C Couplings installed to replace worn couplings with moderate side load -> marginal gains in APPRL and production. Couplings addressing wear issues, but quantities potentially insufficient to recognize low friction benefits.

WELL DATA SUMMARY

WELL EVALUATION

WELL	# CPLGS	WELL DEPTH (FT)	PUMP SZ	PEAK LOAD CHANGE	ADJ. PPRL CHANGE	GROSS STROKE CHANGE	NET LOAD CHANGE	OIL PROD % GAIN/ (LOSS)	AVG. SIDE LOAD - B_4C SECTION	MAX SIDE LOAD - B_4C SECTION
A	100	6,975	1.50	(1541)	(2395)	1	1749	170%	-	-
B	64	7,250	1.75	1480	768	1	147	56%	44.9	71.4
C	120	9,525	1.50	(139)	(122)	3	(246)	-10%	120.3	140.4
D	73	10,450	1.50	(1440)	(888)	21	275	15%	59.7	64.4
E	149	10,175	1.50	(980)	(184)	2	(1176)	93%	146.8	186.6
F	58	6,950	1.75	774	752	7	(53)	22%	21.7	27.9
G	68	10,150	1.25	1204	(1514)	(22)	(1708)	23%	99.8	99.8
H	111	7,625	1.75	(2618)	484	11	(229)	18%	75.0	223.6
I	74	7,075	1.50	(331)	1494	(5)	287	38%	41.2	114.2
J	107	8,200	1.50	929	9	(6)	(240)	13%	46.8	72.0
K	68	9,750	1.50	(788)	510	11	352	2%	106.9	119.5
L	71	9,700	1.50	(39)	94	(2)	1514	-8%	70.7	135.7
M	66	7,200	1.75	(1966)	(1382)	(17)	(10162)	33%	106.9	193.9
N	80	9,983	2.00	(3751)	(459)	8	(217)	-21%	57.7	72.3
O	71	8,425	1.50	(820)	52	2	(288)	-12%	87.8	167.7
P	75	8,200	1.75	(1174)	(423)	(4)	(1150)	15%	122.6	144.2
Q	96	8,850	2.00	(1592)	1012	2	268	-4%	16.7	16.7
R	124	9,975	1.50	(1958)	(2205)	14	(1523)	-51%	-	-
S	92	9,675	1.50	491	1185	4	638	-11%	105.8	145.6
T	57	9,700	1.50	2455	(941)	(25)	25	-5%	70.0	95.8
AVERAGE - ALL WELLS	86	8792	1.60	(590)	(208)	0	(587)	19%	77.9	116.2

- The collection of wells reviewed showed varying performance levels.
- All wells showed some level of improvement following the installation of B_4C couplings.
- **70%** showed a **reduction in peak polished rod load** while **over 60%** of the wells showed a **gain in downhole stroke** and a 41% **BOED improvement** in production.
- Because each well has its own characteristics, it is difficult to pinpoint why some wells showed better lifting efficiency than others.
- The data does suggest that the lower friction of the B_4C couplings contributes to better lifting efficiency.

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MORE COUPLINGS = BETTER PERFORMANCE?

	# CPLGS	WELL DEPTH (FT)	PUMP SZ	PEAK LOAD CHANGE	ADJ. PPRL CHANGE	GROSS STROKE CHANGE	NET LOAD CHANGE	OIL PROD % GAIN/ (LOSS)	AVG. SIDE LOAD - B_4C SECTION	AVG. MAX SIDE LOAD - B_4C SECTION
Average - Wells less than 75 couplings	67	8665	1.55	53	(106)	(3)	(961)	16%	71.0	109.0
Average - Wells with 75 to 100 couplings	86	9177	1.81	(1,507)	329	2	(115)	-5%	75.7	94.7
Average - Wells with Greater than 100 Couplings	119	8746	1.54	(1,051)	(736)	4	(278)	39%	97.2	155.7
Wells Greater than 75 Couplings	105	8918	1.65	(1,233)	(310)	3	(213)	21%	86.5	125.2

- Data suggests that the more B_4C couplings installed within the rod string, the greater lifting efficiency achieved.
- To explore this observation, a lab test was conducted to compare the Coefficient of Friction values of single and double quantities of couplings on L80 Tubing.

LAB EVALUATION – COEFFICIENT OF FRICTION

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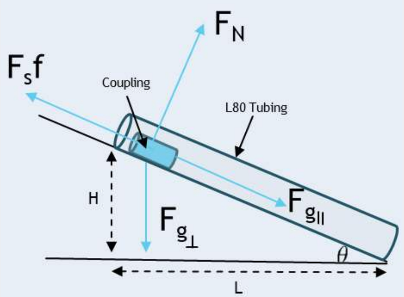
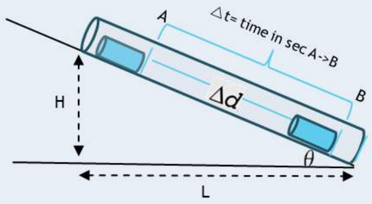
CoF - Static



u_{static} : $H/L = \tan\theta$

CoF - Kinetic



$u_{kinetic}$: $\dfrac{g \sin\theta + a_{||}}{g \cos\theta}$

Where, $a_{||}$ =

$$\Delta d_{\parallel} = v_{\parallel}\Delta t + \frac{1}{2}a_{\parallel}\Delta t^2 = (0)\Delta t + \frac{1}{2}a_{\parallel}\Delta t^2 = \frac{1}{2}a_{\parallel}\Delta t^2$$

$$\Rightarrow 2\Delta d_{\parallel} = a_{\parallel}\Delta t^2 \Rightarrow a_{\parallel} = \frac{2\Delta d_{\parallel}}{\Delta t^2}$$

- To assess the lower friction of B_4C couplings, an experiment was conducted to compare the coefficient of friction (CoF) of B_4C couplings against spray metal and class T couplings on L80 tubing.
- The experiment was conducted in two phases.
- In Phase 1, single couplings were used to calculate the static and kinetic CoF of each coupling using the incline plane method.
- Ten observations of each coupling were recorded and averaged to determine the static and kinetic CoF for each coupling.
- Phase 2 experiment was conducted to determine if additional couplings could influence the CoF overall.
- In Phase 2, two couplings of each type were connected, and the experiment was repeated, observations were recorded and averaged to determine the CoF.

LAB RESULTS - COEFFICIENT OF FRICTION

Coupling - 34FS
Tubing - L80

CoF Results

	COF -u_{static}	COF-$u_{kenetic}$
SINGLE COUPLING	SINGLE	SINGLE
B_4C	0.1816	0.1568
T	0.3073	0.2714
SM	0.1964	0.1678

	COF -u_{static}	COF-$u_{kenetic}$
DOUBLE COUPLING	DOUBLE	DOUBLE
B_4C	0.1679	0.1542
T	0.2728	0.2311
SM	0.1781	0.1660

DOUBLE v SINGLE	COF -u_{static}	COF-$u_{kenetic}$
B_4C	-8%	-2%
T	-11%	-15%
SM	-9%	-1%

Comparative Assessment

	COF -u_{static}	B_4C	T	SM
B_4C	0.1816		-41%	-8%
T	0.3073	69%		56%
SM	0.1964	8%	-36%	

	COF-$u_{kenetic}$	B_4C	T	SM
B_4C	0.1568		-42%	-7%
T	0.2714	73%		62%
SM	0.1678	7%	-38%	

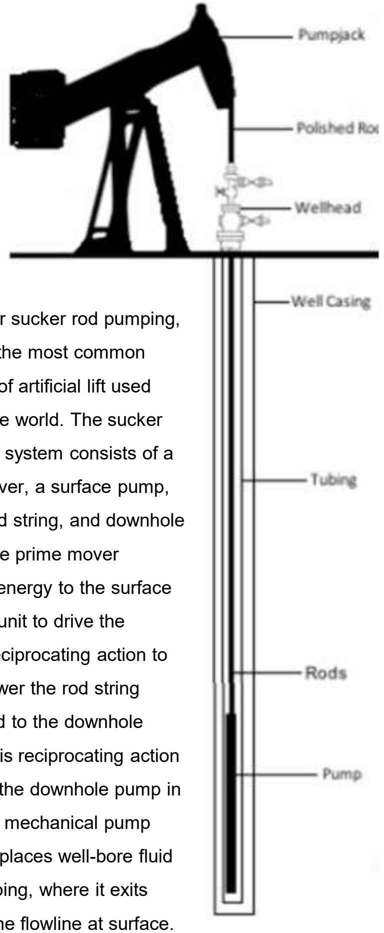
	COF -u_{static}	B_4C	T	SM
B_4C	0.1679		-38%	-6%
T	0.2728	63%		53%
SM	0.1781	6%	-35%	

	COF-$u_{kenetic}$	B_4C	T	SM
B_4C	0.1542		-33%	-7%
T	0.2311	50%		39%
SM	0.1660	8%	-28%	

- As to be expected, kinetic friction was lower than static friction in both Phase 1 (single coupling) and Phase 2 (double coupling) experiments.
- Phase 1 - The B_4C couplings showed lower CoF than both class T and spray metal (SM) couplings – (-41% and -8%) for static and (-42% and -7%) for kinetic respectively.
- Phase 2 - The B_4C couplings showed lower CoF than both class T and spray metal (SM) couplings – (-38% and -6%) for static and (-33% and -7%) for kinetic respectively.
- Given the small sample and potential error in time keeping, it is difficult to assess whether additional couplings lead to lower friction overall; however, the data does suggest it is plausible.

Lab evaluation demonstrates B_4C couplings exhibit lower static and kinetic friction compared to class T and SM couplings.

IMPORTANCE OF LIFTING EFFICIENCY



Rod lift, or sucker rod pumping, is one of the most common methods of artificial lift used around the world. The sucker rod pump system consists of a prime mover, a surface pump, sucker rod string, and downhole pump. The prime mover provides energy to the surface pumping unit to drive the vertical reciprocating action to lift and lower the rod string connected to the downhole pump. This reciprocating action operates the downhole pump in which the mechanical pump action displaces well-bore fluid up the tubing, where it exits through the flowline at surface.

- Many prime movers are electrical and consume a significant amount of energy to power the rod pump system.
- The monthly electrical bill is typically a large contributor to lease operating expenses >>> system and lifting efficiency are of utmost importance to the production engineer.
- **Friction has a significant influence on the lifting efficiency** and operating costs of an SRP system.
- The **friction from the downhole drag** of components against the tubing not only **causes mechanical wear**, but also results in **higher energy consumption**.
- **Lessening friction** throughout the system **can improve** equipment **reliability**, **run-times**, and **reduce** the **energy** required to operate the system.

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LEVERAGING TECHNOLOGY

B_4C Couplings

- The engineered surface has a reduced coefficient of friction, is extremely abrasion resistant, and has excellent corrosion resistant properties.
- This combination of features enables B_4C treated parts to last longer than untreated parts in challenging conditions.

SUMMARY

- Chesapeake uses B_4C couplings to address mechanical wear and abrasion issues in their SRP wells – improved lifting efficiency and increased production is viewed as an ancillary benefit of their use.
- Of the twenty wells evaluated, 70% showed a reduction in peak polished rod load while over 60% of the wells showed a gain in downhole stroke and a 41% BOED improvement in production. The improved lifting efficiency was attributed to lower friction in the rod string due to the use of B_4C couplings.
- Since the initial evaluation, Chesapeake has deployed several thousand more couplings across the asset base and now has B_4C couplings installed in over 170 wells.
- Of all the installations thus far, there have been zero coupling or tubing failures associated with the use B_4C couplings.

170 wells

- 14% - over 18 months run-time
- 35% - between 12 months and 18 months run-time
- 51% - installed within the last 12 months

Acknowledgements, Thank You & Questions

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Sources

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