CASE STUDY: USE OF CAPILLARY CO_2 ASSISTED STRINGS FOR ARTIFICIAL LIFT AT THE ADAIR SAN ANDRES UNIT, TERRY AND GAINES COUNTIES, TEXAS

R. Larkin, J. Lopez, and J. Roberts

Apache Corporation

ABSTRACT

The Apache-operated Adair San Andres Unit (ASAU) currently employs seventeen capillary string (cap string) equipped producing wells, representing 19% of the active producer count. Apache started converting producing wells to cap strings in 2016. This idea was introduced to Apache at the 2012 CO_2 Conference in Midland and later reinforced during a field tour of Whiting's North Ward Estes CO_2 flood in 2015. The chief benefit using a cap string is production stability. A review of these installations is categorized by a reduction in production variance, meaning an increase in stability - be it oil and gas production, or water-oil and gas-liquid ratio (GLR). This equates to less rig intervention, more uptime. Of note: 1) a cap string will successfully operate below the minimum GLR of 400 SCF/BBL/1000' required by plunger lift, 2) conversion to cap string assisted lift is not affected by the wellbore geometry, and 3) ASAU installations are packer-less.

INTRODUCTION

The Adair San Andres Unit is located approximately 48 miles southwest of Lubbock, Texas and straddles Terry and Gaines Counties. Geologically, it is a Permian-age carbonate build-up (San Andres) along the regional Horseshoe Atoll complex [Map 1].

Discovered in 1947, ASAU was unitized in 1962, with waterflooding starting in 1963 and CO_2 flooding in 1997; Apache became unit operator in 2006. ASAU produces a paraffinic oil. Despite being undersaturated at discovery, records indicate that by 1950, reservoir pressure dropped sufficiently to require routine paraffin cutting in the production tubing and paraffin scrapers attached to the sucker rods. Huber paddles and Crawl spiral scrapers were in common use. Paraffin abatement/removal continues to be a leading operating cost to this day, only surpassed by electrical power.

The pay zone is described as a series of upward shallowing carbonate cycles grading upward from deeper subtidal mudstones and wackestones into higher energy deposited tight packstones and grainstones [Reference 1]. The rock is mostly dolomite, with anhydrite present throughout and forming a cap rock seal as well. Rehydrated anhydrite forms gypsum, or gyp scale, which must be converted to an acid soluble product for removal. Gyp scale precipitates with pressure drop in wellbores and surface facilities. Its inhibition/removal also is a significant contributor to operating expense at ASAU.

CAPILLARY CO_2 ASSISTED STRING (CCAS)

Apache personnel were introduced to capillary strings in this context for artificial lift at the 2012 CO_2 Conference in Midland, Texas [Reference 2]. Mr. Edward Payne of Whiting Oil & Gas and inventor of the technique gave our personnel a field tour of their North Ward Estes CO_2 flood in 2015 [Reference 3]. We adopted the technique in general and installed the first two systems in 2016. Our wellhead setup is similar to Whiting's [Figure 1]; however, we do not use a packer and worked with a local machine shop to develop an injection lift tool (three size options are currently available) [Figure 2]. Because of the paraffinic nature of the oil and gyp scaling potential at ASAU, we decided to retain the option to chemically treat the casing-tubing annulus in CCAS wells. At the time of this writing, there are seventeen CCAS producers at ASAU, labelled A through Q, representing 19% of active producing wells [Map 2]. So far, our experience at ASAU finds CCAS producers to be more reliable now than with their former lift methods. To date only one well needed a rig intervention following conversion. The capillary string plugged up on Well G shortly after installation due to a vendor error splicing 3/8" string segments together. Well G is unique in that it was converted from intermittent flowing to CCAS one month following initial completion. However, we cleaned out frac sand and gyp scale and it is trouble-free since then.

Downhole equipment consists one or more strings of 3/8" stainless-steel tubing strapped to bare J-55 production tubing. Inline in the production tubing at the terminus of each capillary string is an injection tool. Below the tool is a stainless-steel profile nipple then several spacing joints of production tubing, several joints of same size fiberglass tubing, typically to span pay zone perforations and finally an off-the-shelf centralizer. As such, wellbore geometry has not limited installation or affect performance. The number of capillary strings is determined by depth and volume of fluid required to lift. Capillary strings handle to up 200 MCFPD of injection per string. Surface injection volume required varies with influx to the wellbore; with enough influx surface injection may be temporarily suspended. Capital outlay cost for surface and downhole equipment is relatively low; surface injection line cost is relative to length to source; availability and cost of injectant are the largest cost drivers for this method.

CCAS work by combining the lift benefits of transitioning between foam, energized foam and energized fluid as production flowing up the tubing string. This minimizes the opportunity for liquid loading and fluid fallback to occur [Figure 3, Reference 4]. Stable production should result.

Having an energized fluid available is key. No foaming agent is added to the injectant to stabilize the created foam, here recycled CO_2, however, CO_2 is soluble in both oil and water, so as the foam degrades, solubility and energy remain to lift. Lift energy may be inferred looking at the nonlinear change in density with pressure drop for a supercritical CO_2 : methane mixture, similar to the recompressed recycle stream at ASAU, compared to that of linear pure methane [Figure 4]. The colder the mixture the better too. Enthalpy of CO_2 is less than that of methane; it may not burn but it can do considerable work.

CANDIDATE SELECTION

Candidate selection involves two chief criteria: 1) downtime production losses in excess of neighboring wells and 2) production swings induced by WAG (water alternating gas) cycles. Downtime production losses are frequently because of paraffin buildup: tubing plugs off and must be cut open with a paraffin knife and/or dissolved with solvent in hot water. Some wells several times per week. Pumps prefer liquid to gas, separators can help sucker rod and electric submersible pumps (ESP) handle CO2 half-cycles that "dry out" production streams up to a point, but failure rates tend to rise. Following change in operatorship, Apache has taken a more aggressive approach to the CO_2 flood at ASAU. From the standpoint of artificial lift, this results in more frequent changes in lift type. Figures 5A and 5B illustrate these changes specific to the wells converted to CCAS.

CCAS PERFORMANCE

To fairly compare performance before and after conversion to CCAS, equal pre- and post-time periods are used. Post-time is fixed starting at conversion and ending at the time of this writing. Graphs of before and after oil production, cumulative oil, gas-liquid and water-oil ratios, and SCF gas per barrel liquid per 1000' of depth follow. The full post-time for Well G is included in all but the oil plots, which forecast trends.

Apparent noise in oil production is indicative of downtime; visually, after conversion, the curves are less noisy [Figure 6]. Figure 7 rollups up all before and after oil production curves to one curve each. After conversion, downtime is minimal although WAG cycle swings remain.

Plotting the cumulative oil production trends of each well before and after conversion, averaging them and plotting the resultant vector suggests that these wells will produce more oil with CCAS than without [Figure 8].

Gas liquid ratio (GLR) and water oil ratio (WOR) became more stable after CCAS installation [Figure 9 and Figure 10].

Lastly, over half of the CCAS wells will sustain production below the 400 SCF/barrel/1000 feet of depth threshold recommended by the plunger lift method [Figure 11 and Reference 5]. Having an energized fluid available for lift may explain this behavior.

SPECIFIC WELL CASE HISTORIES

Two of the wells are highlighted, Well C and K. Well C is the first well converted to CCAS in July 2016. It is unique in that it is the only CCAS well to have one lift string and one chemical injection string [Figure 12]. Until recently we did not need to use the chemical string, but have started continuous paraffin inhibitor as a precaution. Well C flowed for only two weeks following its initial potential test in January 1948. It pumped with sucker rods until January 1993. Most of the events labelled "Minor Job" are downhole failures, making this a high failure rate well [Figure 13]. A less failure prone jet pump operated between January 1993 unit June 2000; however, CO_2 contaminated the power fluid, and fearing the risk of an environmental release, it was returned to sucker rods. Reservoir pressure built sufficiently from flooding activity to cause the well to flow naturally in July 2005. Rods were pulled and a packer installed the following month. The well continued to flow until October 2015 when flow became intermittent and total fluid production fell to 60 BPD. Incidentally, intermittent flow and drop in total fluid production is typical of all flowing to CCAS well conversions. The packer was pulled and a CCAS installed in July 2016 without clean out or stimulation of the wellbore, or as mentioned, any downhole rig intervention since. Oil and total fluid production have actually improved in the last six months.

Well K is one of two wells which replaced an ESP with a CCAS (well P is the other well). It has two capillary lift strings as a result [Figure 14]. It flowed naturally from May until August 1948 then employed sucker rods until August 1979. A landowner agreement put in effect requires either a low-profile surface installation or other surface considerations (such as cash payments) because the well lies with an irrigated crop circle. An ESP was installed and run (including replacement units) until the CCAS in early 2017. A summary of its history this century reveals five major and minor rig inventions, including casing repair, casing liner installation, stimulations and ESP replacements [Figure 15]. The well briefly flowed following a slickwater fracture stimulation in February 2013. On CCAS we are saving the incremental cost of electricity (here an ESP uses more kwh than the equivalent to compress up to 400 MCFPD of CO_2) and potential failed equipment replacement while continuing to avoid other surface considerations to the landowner.

SUMMARY

Capillary CO_2 assisted strings are proving to be a cost-effective solution for artificial lift at the Adair San Andres Unit for wells with higher than normal downtime and/or those negatively impacted by WAG cycles. For the current seventeen equipped wells, forecasted normalized cumulative oil production will be greater with these strings than with their prior production mode.

REFERENCES

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3. Payne, E., 2015, North Ward Estes Field Tour November 16, 2015.
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5. Ferguson, P.L. and Beauregard, E., 1983, Will Plunger Lift Work in My Well?, Proceedings, Thirtieth Annual Southwestern Petroleum Short Course, Lubbock, TX, p. 301-311.

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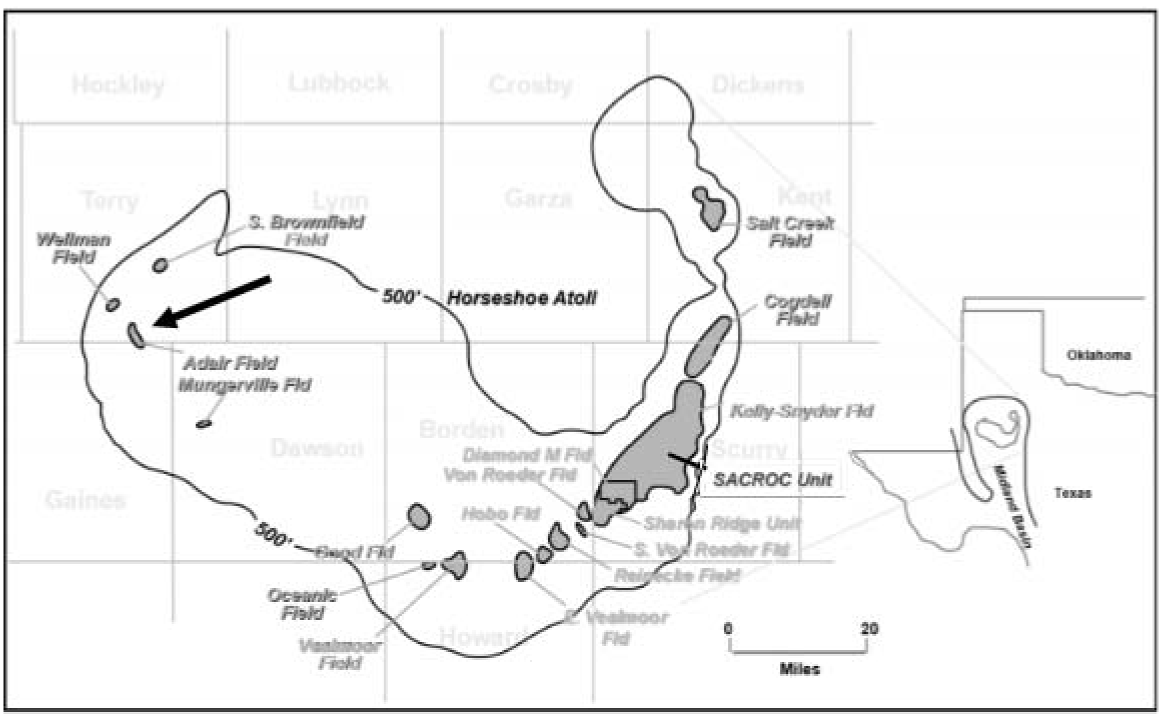
Portales
Plainview
27
Lubbock
Levelland
Roswell
Adair Oil Field
Artesia
Hobbs
Carlsbad
Andrews
20
Abilene
Big Spring
Midland
Odessa
Monahans
Pecos
San Angelo
TEXAS
Horn
10
Fort Stockton


Hockley
Lubbock
Crosby
Dickens
Terry
Lynn
Garza
Kent
Wellman Field
S. Brownfield Field
500'
Horseshoe Atoll
Salt Creek Field
Cogdell Field
Adair Field
Mungerville Fld
Kelly-Snyder Fld
Dawson
Borden
Scurry
Diamond M Fld
Von Roeder Fld
SACROC Unit
Gaines
Hobo Fld
Sharon Ridge Unit
S. Von Roeder Fld
500'
Good Fld
Reinecke Field
Oceanic Field
E. Vealmoor Fld
Vealmoor Field
Howard
0
20
Miles
Oklahoma
Texas
Midland Basin

Map 1

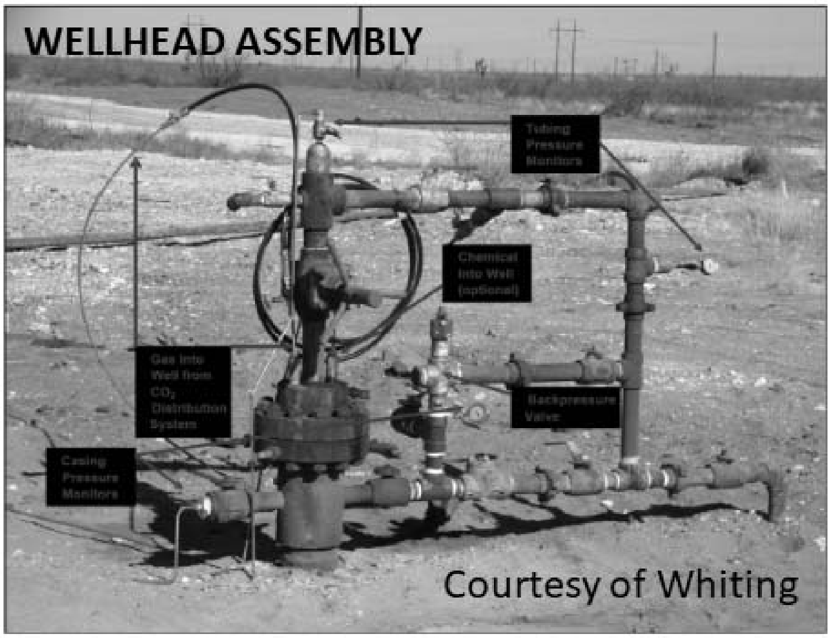


Figure 1

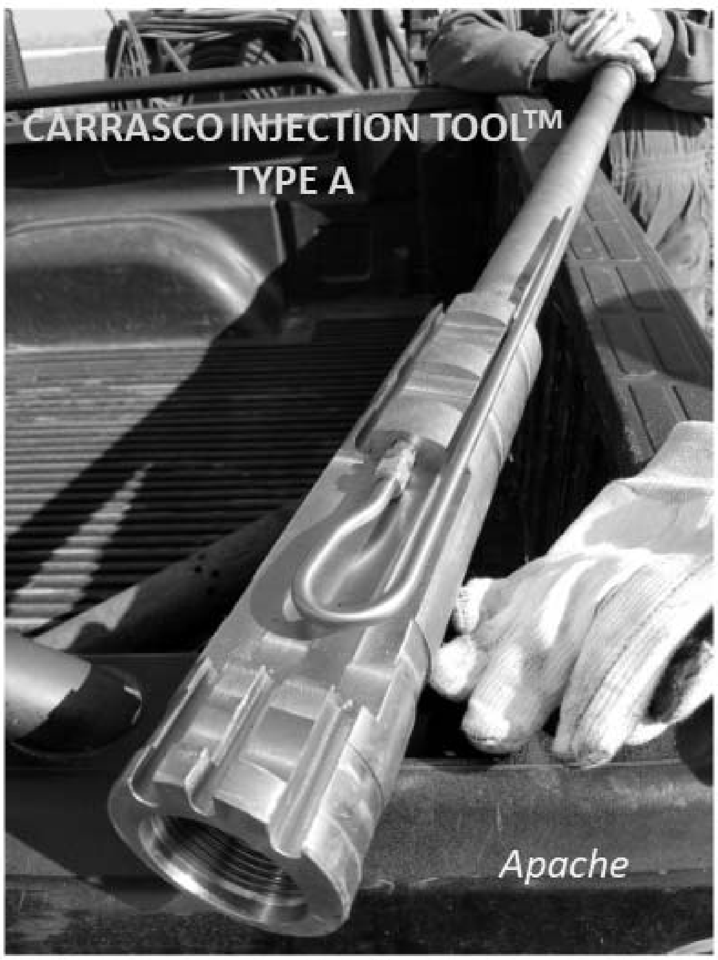
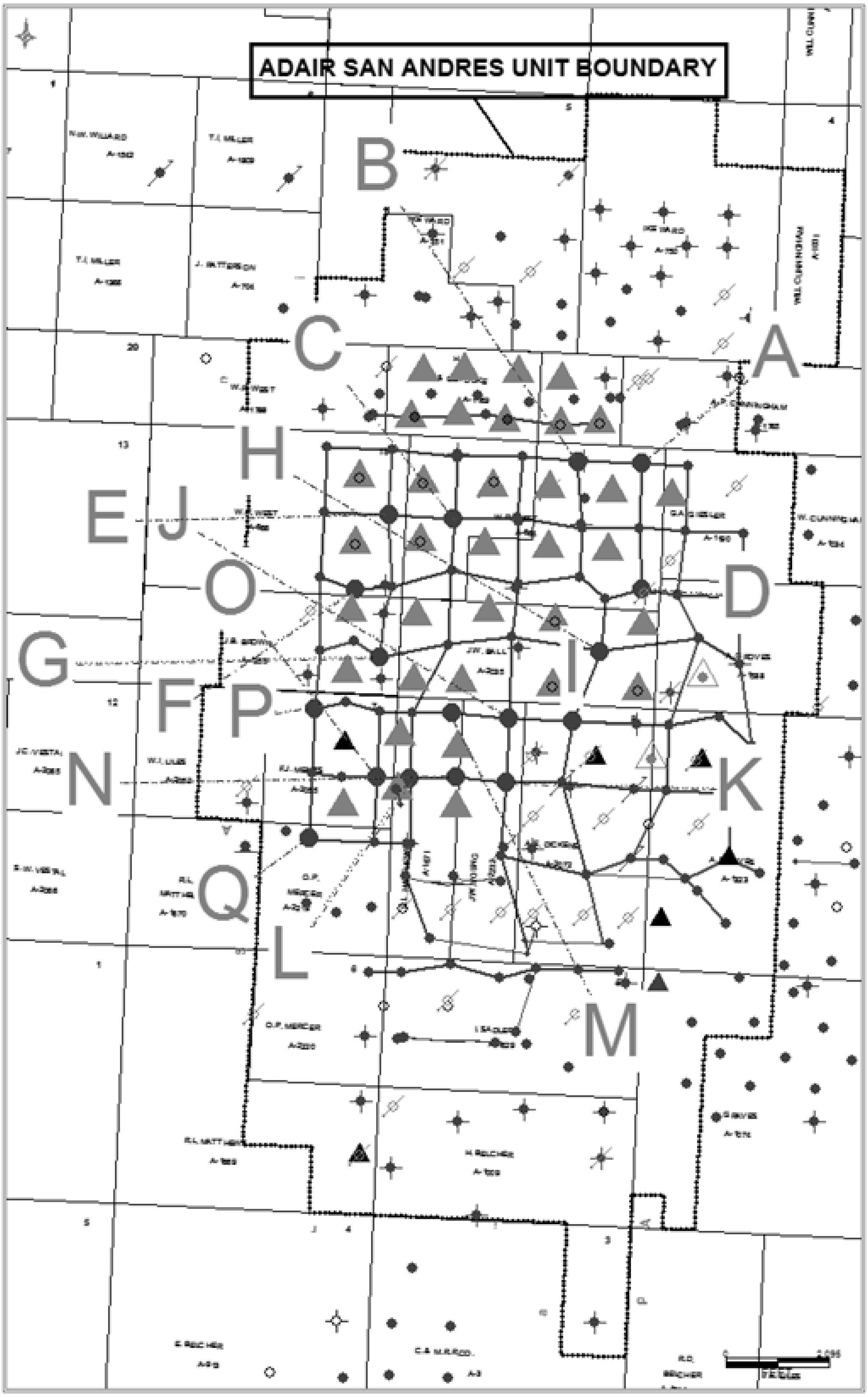


Figure 2



Map 2

FLOW REGIMES AT WORK

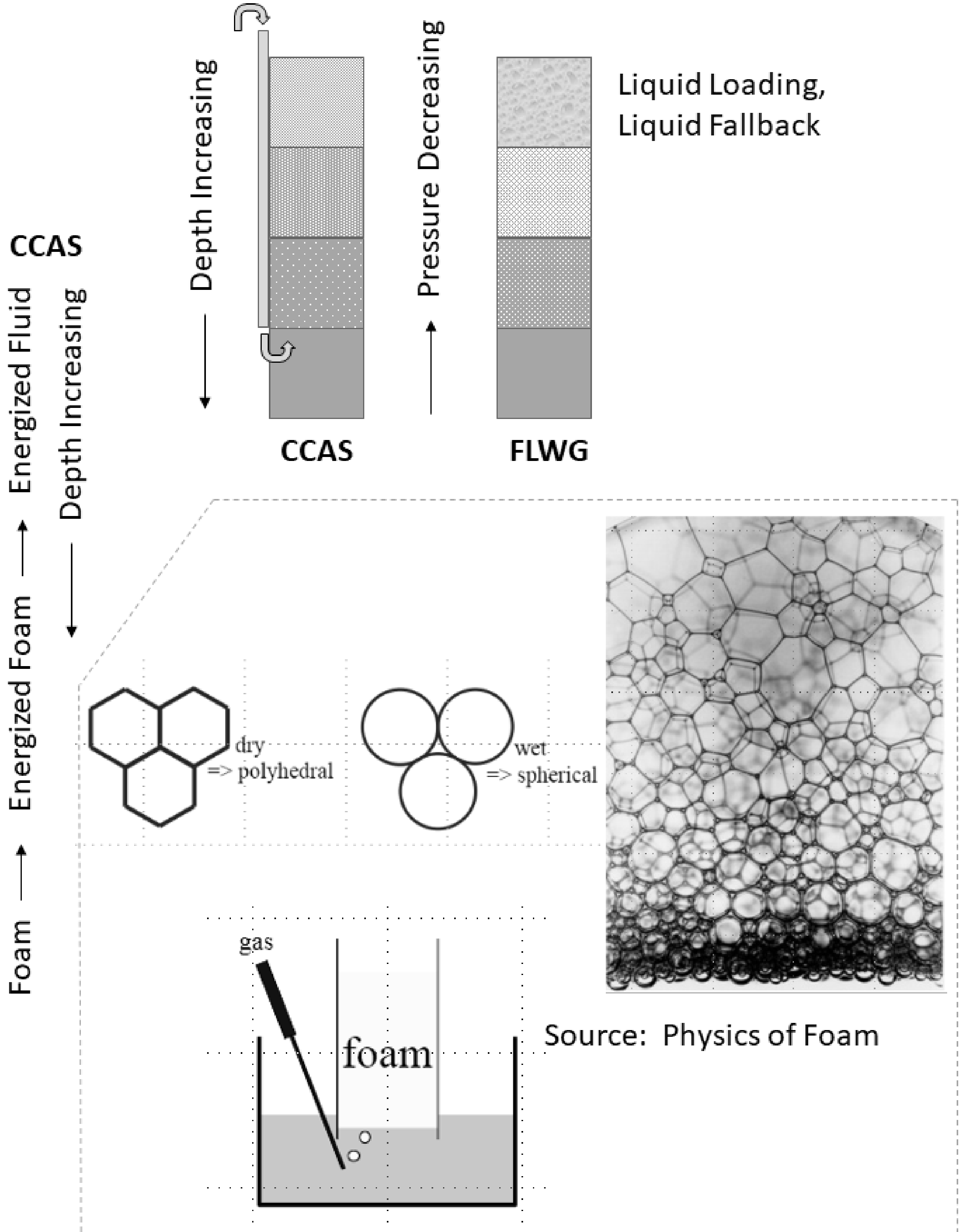


Figure 3

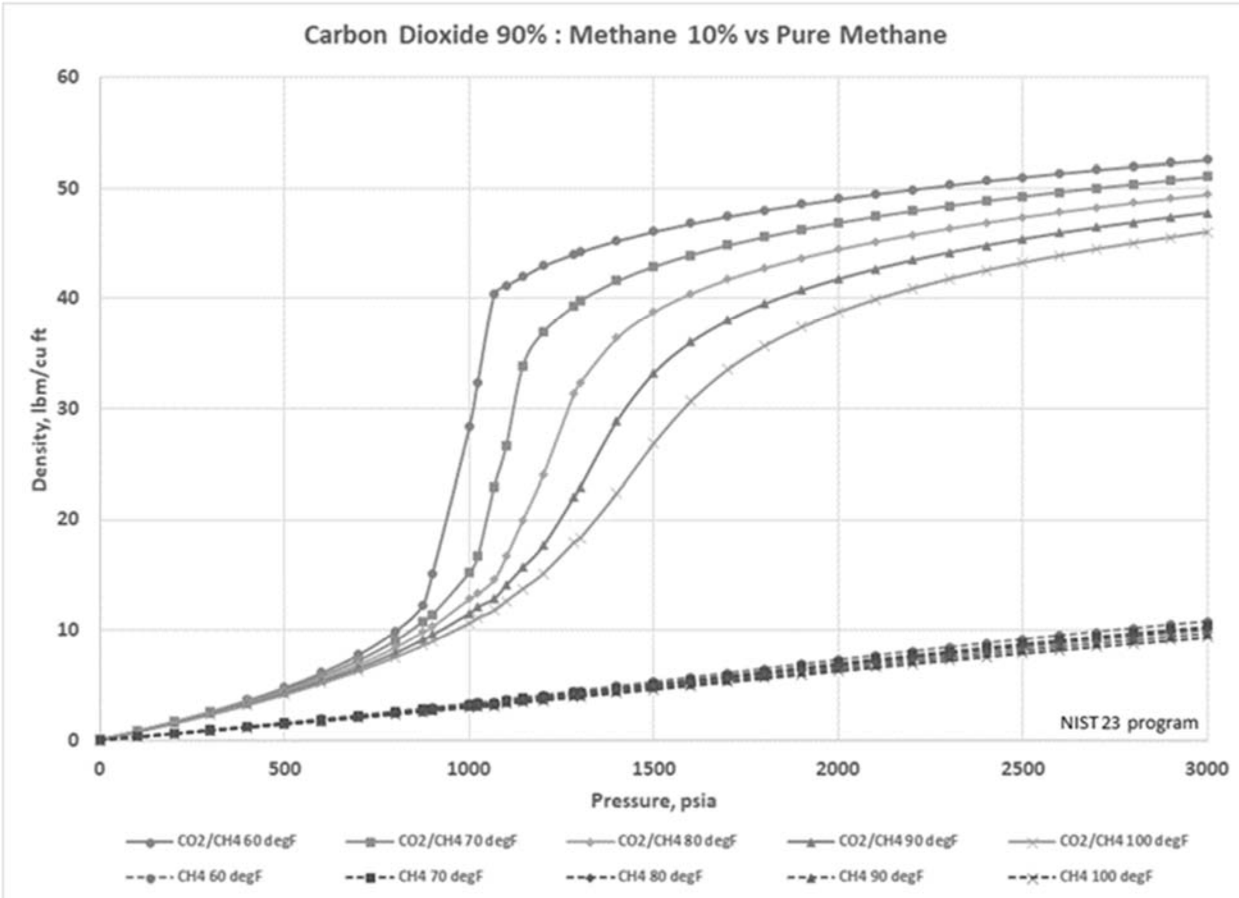

Carbon Dioxide 90% : Methane 10% vs Pure Methane
Density, lbm/cu ft
Pressure, psia
NIST 23 program
0
10
20
30
40
50
60
0
500
1000
1500
2000
2500
3000
CO2/CH4 60 degF
CO2/CH4 70 degF
CO2/CH4 80 degF
CO2/CH4 90 degF
CO2/CH4 100 degF
CH4 60 degF
CH4 70 degF
CH4 80 degF
CH4 90 degF
CH4 100 degF

Figure 4

Lift Timeline of Current Wells on Capillary CO2 Assisted Strings (CCAS)											
Well	Initial Completion	Start	End	Years On Method	Idle	Sucker Rod	Jet Pump	ESP	Flowing	Plunger Lift	CCAS
A	1947	Jul 1947	Nov 1959	12.33					Y		
		Nov 1959	Feb 2011	51.25		Y					
		May 2011	Dec 2012	1.55					Y		
		Dec 2012	Dec 2015	2.99				Y			
		Dec 2015	Feb 2016	0.17					Y		
		Mar 2016	Aug 2016	0.45		Y					
		Aug 2016	Feb 2017	0.47						Y	
		Feb 2017	Jan 2018	0.87		Y					
		Jan 2018		1.13							Y
B	1995	Sep 1995	Oct 2002	7.08		Y					
		Oct 2007	Mar 2017	9.45					Y		
		Mar 2017		1.91							Y
C	1948	Jan 1948	Jan 1993	45.01		Y					
		Mar 1993	Jun 2000	7.29			Y				
		Jun 2000	Jul 2005	5.09		Y					
		Aug 2005	Jul 2016	10.95					Y		
		Jul 2016		2.61							Y
D	2001	Jul 2001	Dec 2004	3.44		Y					
		Dec 2004	Feb 2005	0.10					Y		
		Feb 2005	Nov 2006	1.76		Y					
		Nov 2006	Oct 2018	11.90					Y		
		Nov 2018		0.31							Y
E	1948	Mar 1948	Jun 2004	56.23		Y					
		Jun 2004	May 2018	13.89					Y		
		Jun 2018		0.74							Y
F	2017	Sep 2017	Nov 2018	1.17				Y			
		Dec 2018		0.19							Y
G	2017	Oct 2017	Nov 2017	0.11					Y		
		Dec 2017		1.24							Y
H	1975	May 1975	Mar 2011	35.83		Y					
		Jun 2011	Dec 2012	1.46					Y		
		Dec 2012	May 2017	4.37		Y					
		Jun 2017	Oct 2017	0.37					Y		
		Oct 2017		1.34							Y
I	1948	May 1948	Jun 2013	65.07		Y					
		Aug 2013	Mar 2017	3.55					Y		
		Mar 2017		1.94							Y
J	1948	May 1948	Aug 1948	0.25					Y		
		Aug 1948	Feb 2008	59.49		Y					
		Mar 2008	Oct 2017	8.62					Y		
		Dec 2016		2.19							Y

Figure 5A

Lift Timeline of Current Wells on Capillary CO2 Assisted Strings (CCAS)											
Well	Initial Completion	Start	End	Years On Method	Idle	Sucker Rod	Jet Pump	ESP	Flowing	Plunger Lift	CCAS
K	1948	May 1948	Aug 1948	31.24					Y		
		Aug 1948	Aug 1979	64.47		Y					
		Aug 1979	Feb 2013	39.52				Y			
		Mar 2013	Apr 2013	-33.46					Y		
		Apr 2013	Feb 2017	-15.54				Y			
		Mar 2017		1.98							Y
L	1949	Jan 1949	Sep 1979	30.63		Y					
		Sep 1979	Sep 1997	18.02				Y			
		Oct 1997	Jan 1998	0.27					Y		
		Jan 1998	Mar 2011	13.13				Y			
		Mar 2011	Sep 2011	0.51					Y		
		Nov 2011	Nov 2015	3.99				Y			
		Nov 2015	Oct 2018	2.86					Y		
		Oct 2018		0.35							Y
M	2004	Dec 2004	Nov 2016	11.93					Y		
		Dec 2016		2.21							Y
N	2006	Mar 2006	Apr 2007	1.07				Y			
		Apr 2007	Jun 2017	10.11					Y		
		Jun 2017		1.71							Y
O	1948	Sep 1948	Oct 1948	0.05					Y		
		Oct 1948	Jan 2008	59.21		Y					
		Jan 2008	Jan 2009	1.03				Y			
		Jan 2009	Mar 2010	1.07						Y	
		Apr 2010	Oct 2010	0.58		Y					
		Nov 2010	Jul 2015	4.64					Y		
		Jul 2015	Mar 2018	2.72		Y					
		Apr 2018		0.86							Y
P	1948	Oct 1948	Jan 1949	0.27					Y		
		Jan 1949	Mar 1971	22.15		Y					
		Apr 1971	Aug 1974	3.42	Y						
		Sep 1974	Apr 2011	36.64		Y					
		Aug 2011	Apr 2018	6.69				Y			
		May 2018		0.75							Y
Q	1949	Feb 1949	Mar 1949	0.04					Y		
		Mar 1949	Jan 1988	38.81		Y					
		Jan 1988	Jul 1989	1.53	Y						
		Jul 1989	Apr 2018	28.73		Y					
		May 2018		0.79							Y

Figure 5B

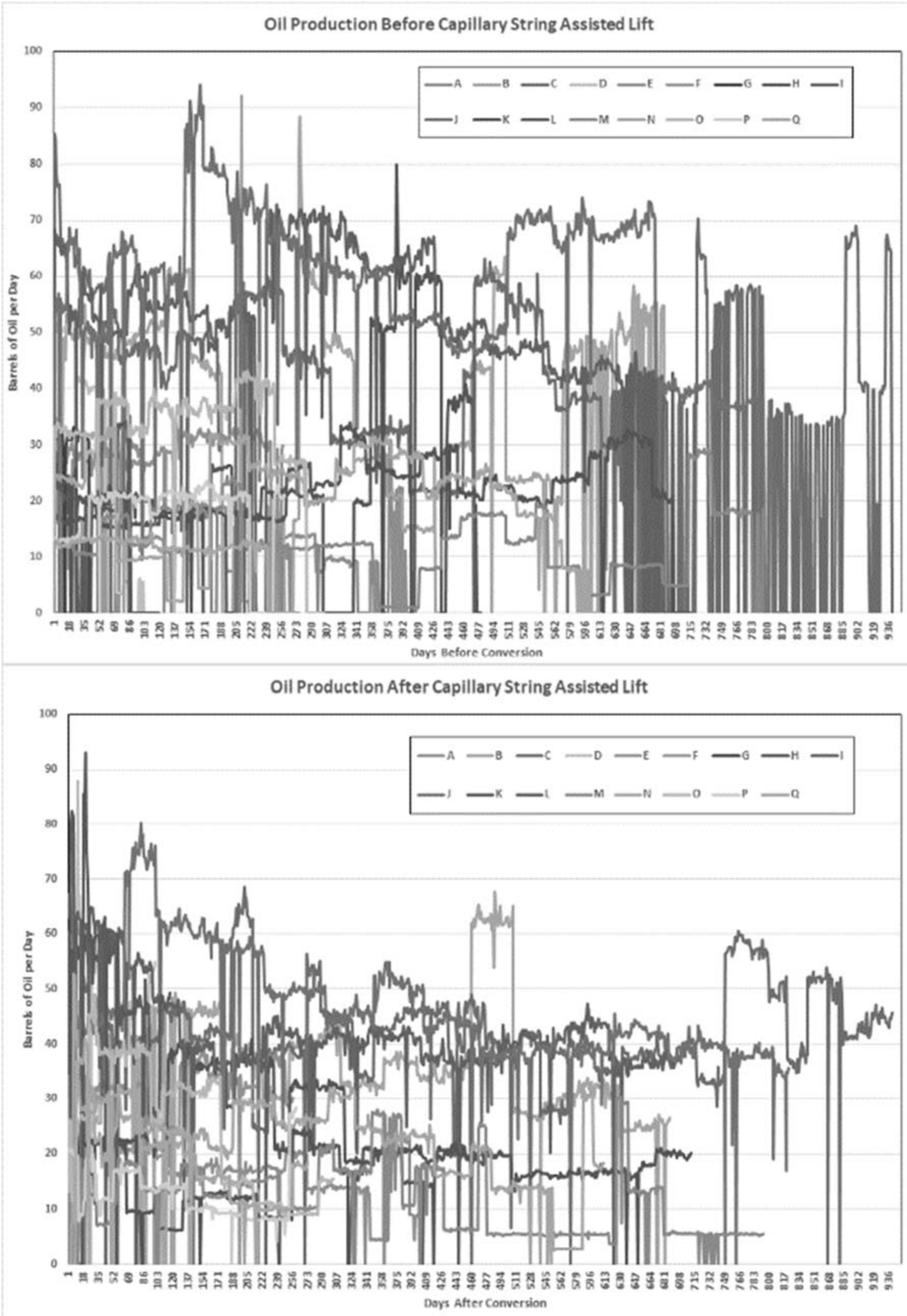
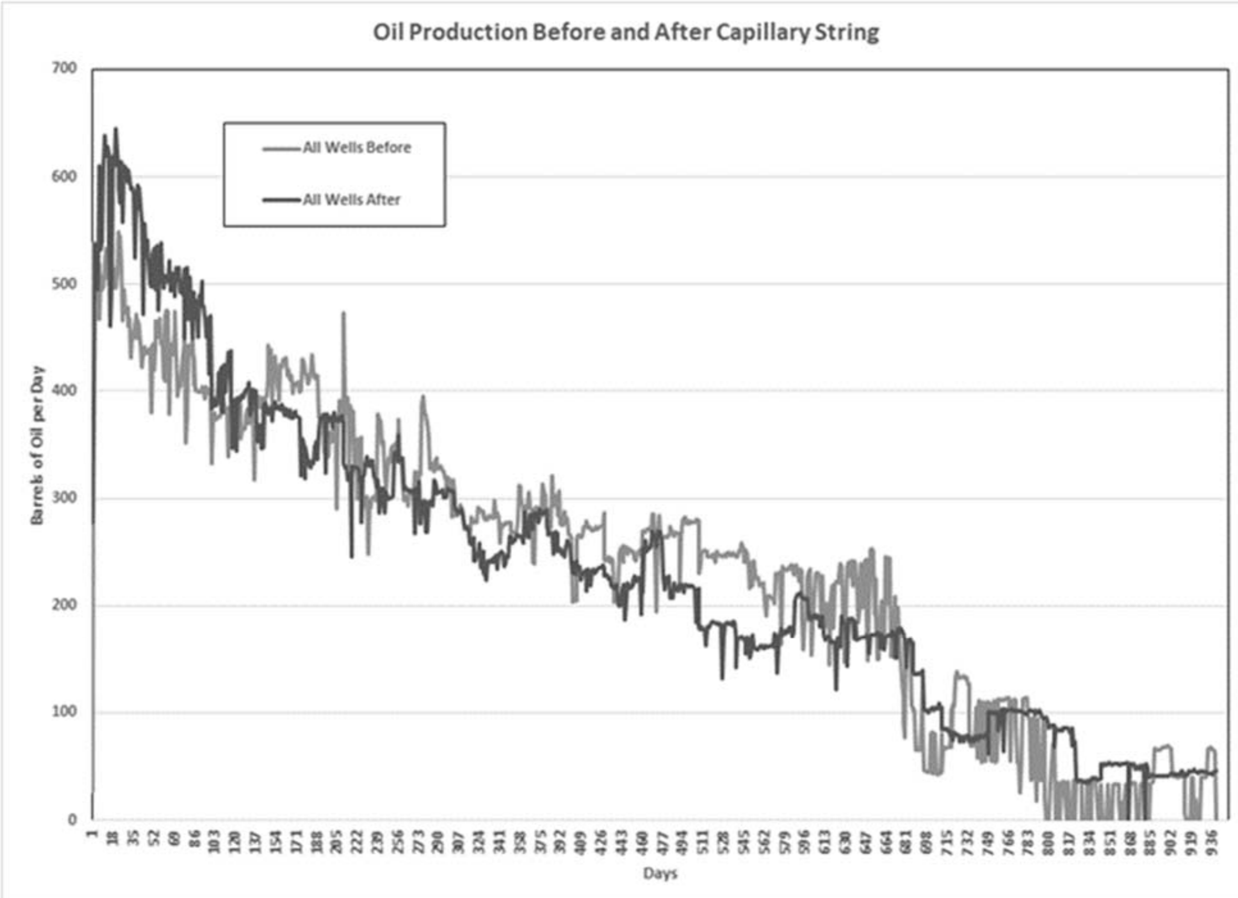
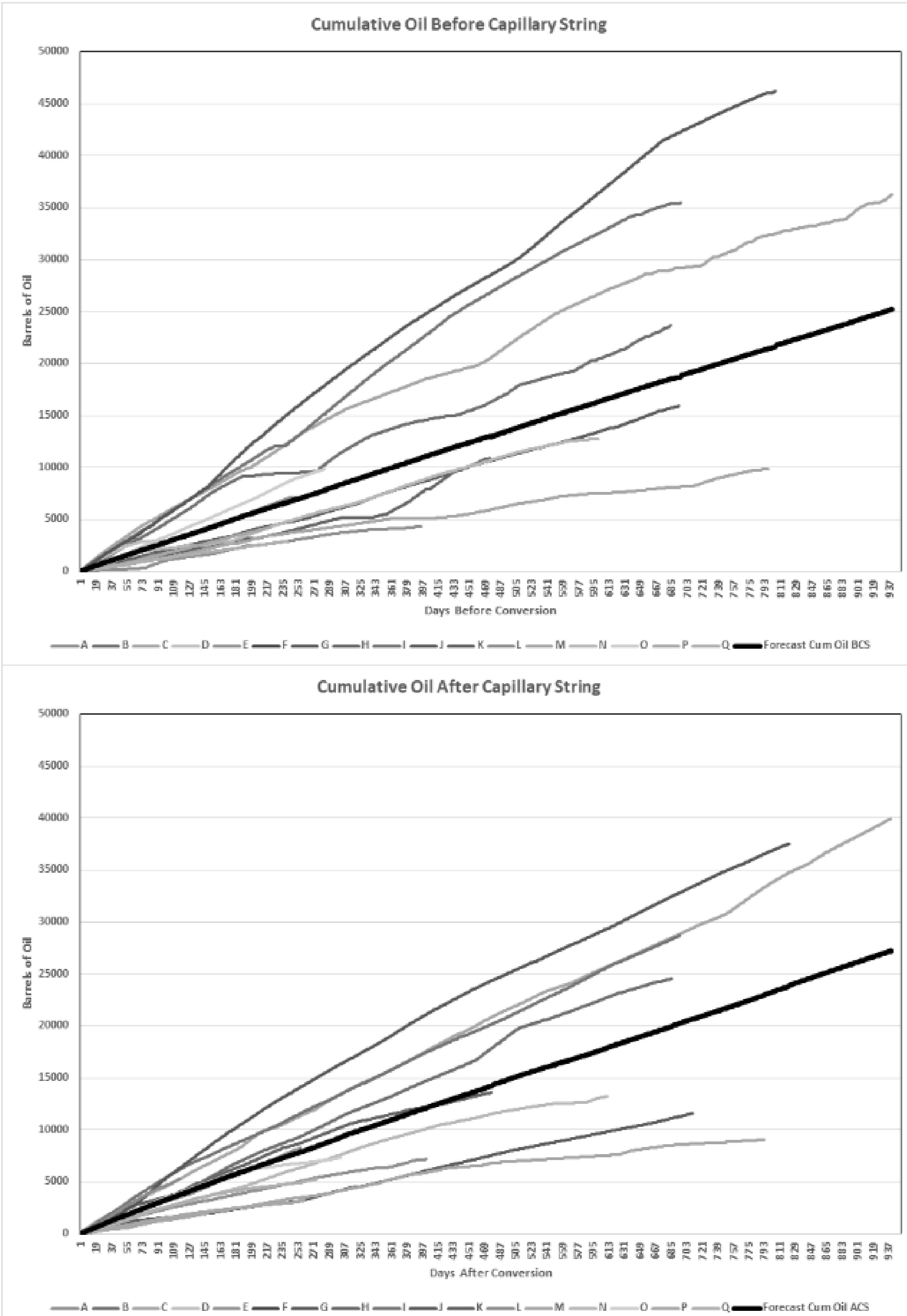

Oil Production Before Capillary String Assisted Lift
Barrels of Oil per Day
Days Before Conversion
A B C D E F G H I
J K L M N O P Q
Oil Production After Capillary String Assisted Lift
Barrels of Oil per Day
Days After Conversion
A B C D E F G H I
J K L M N O P Q

Figure 6



Oil Production Before and After Capillary String
All Wells Before
All Wells After
Barrels of Oil per Day
Days

Figure 7



Cumulative Oil Before Capillary String
Barrels of Oil
Days Before Conversion
A B C D E F G H I J K L M N O P Q Forecast Cum Oil BCS
Cumulative Oil After Capillary String
Barrels of Oil
Days After Conversion
A B C D E F G H I J K L M N O P Q Forecast Cum Oil ACS

Figure 8

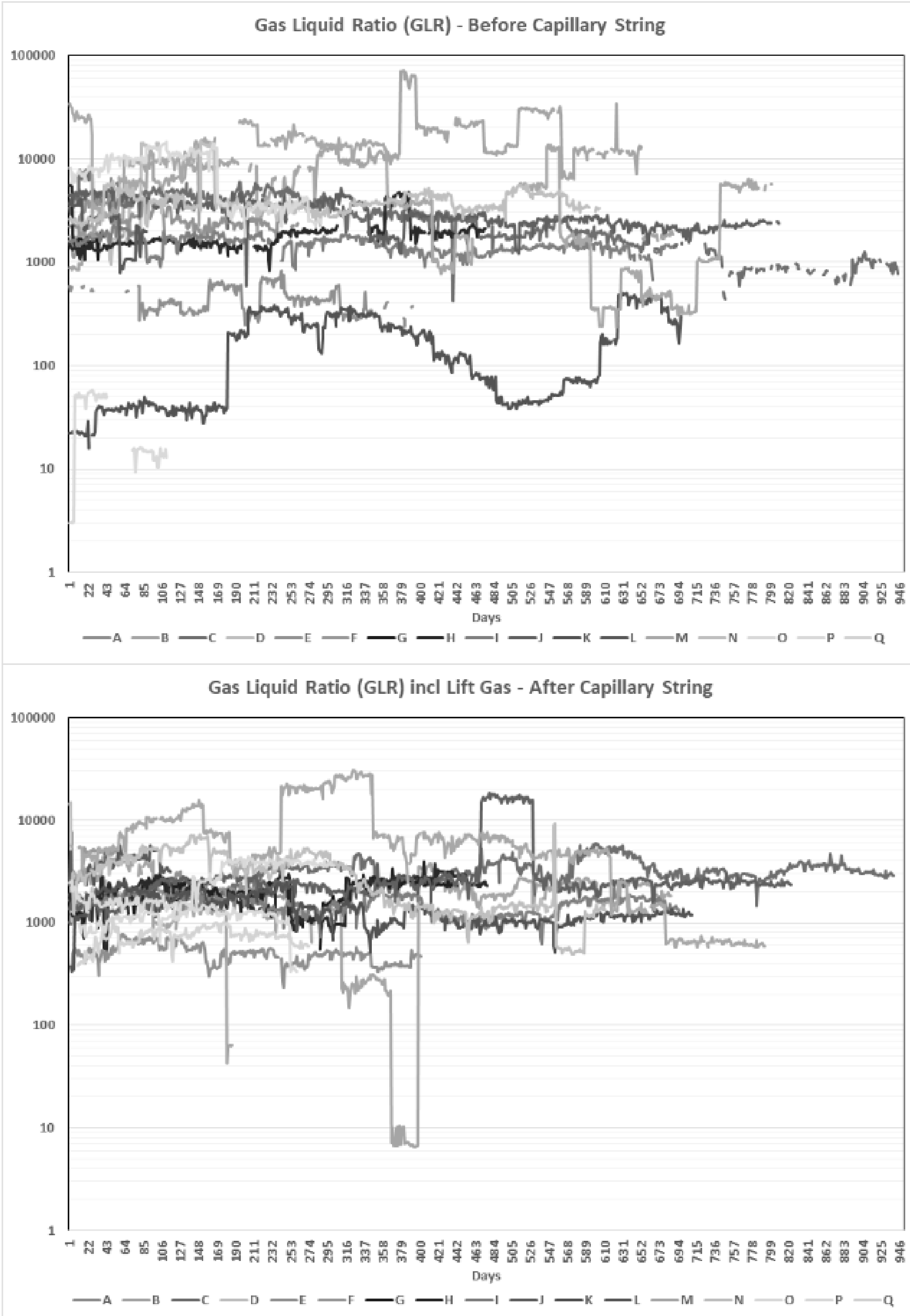
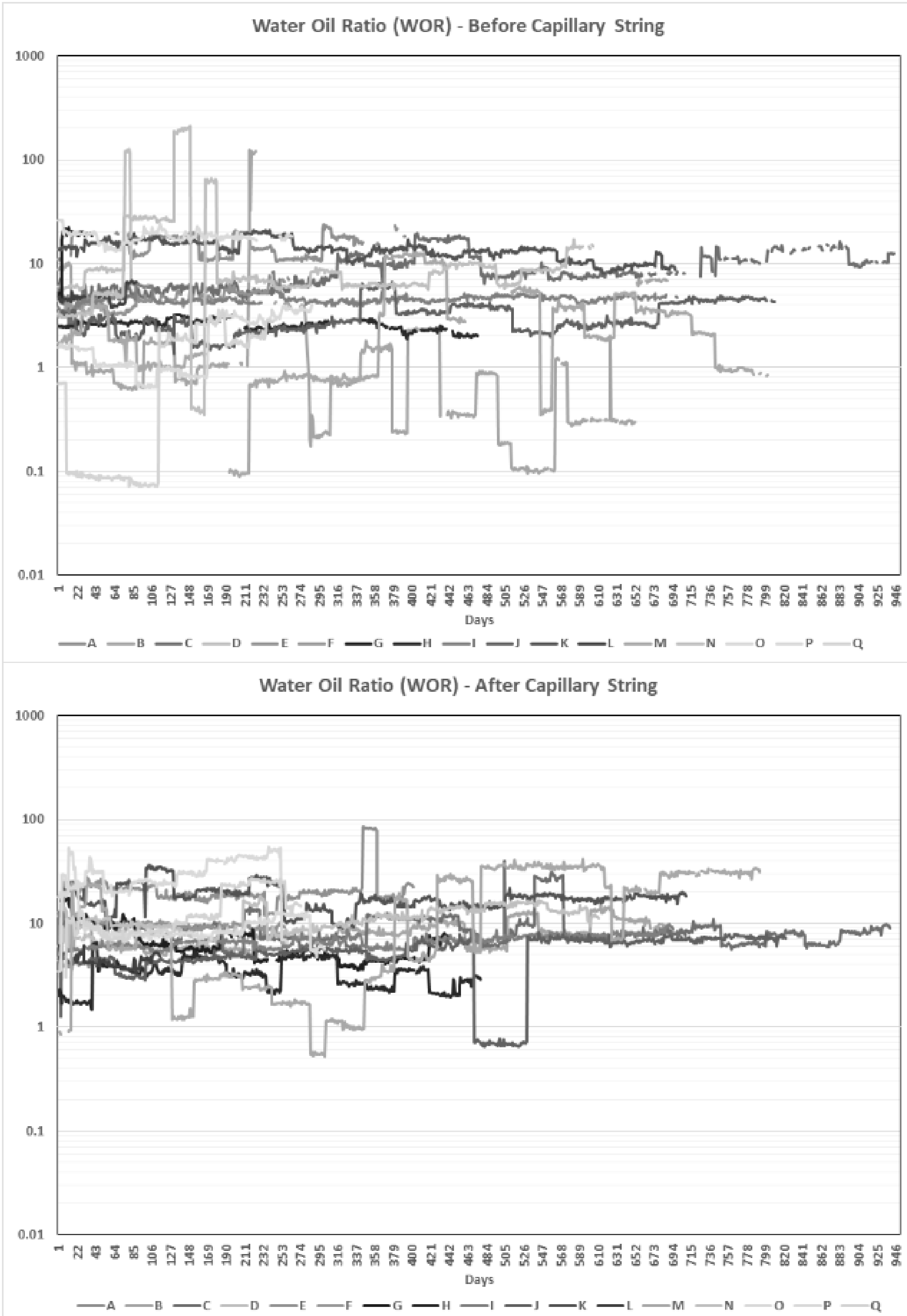

Gas Liquid Ratio (GLR) - Before Capillary String
100000
10000
1000
100
10
1
Days
A B C D E F G H I J K L M N O P Q
Gas Liquid Ratio (GLR) incl Lift Gas - After Capillary String
100000
10000
1000
100
10
1
Days
A B C D E F G H I J K L M N O P Q

Figure 9



Water Oil Ratio (WOR) - Before Capillary String
1000
100
10
1
0.1
0.01
Days
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
Water Oil Ratio (WOR) - After Capillary String
1000
100
10
1
0.1
0.01
Days

Figure 10

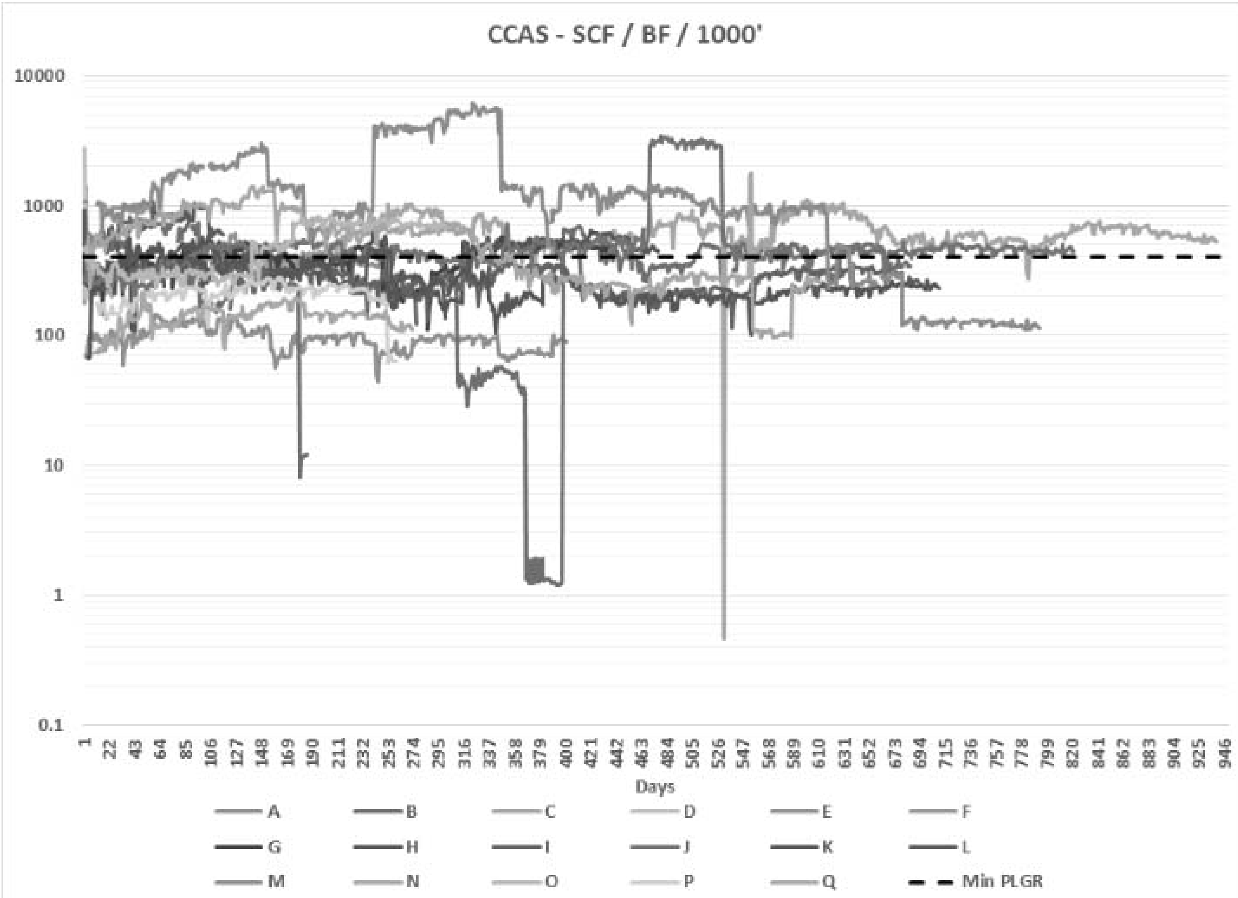
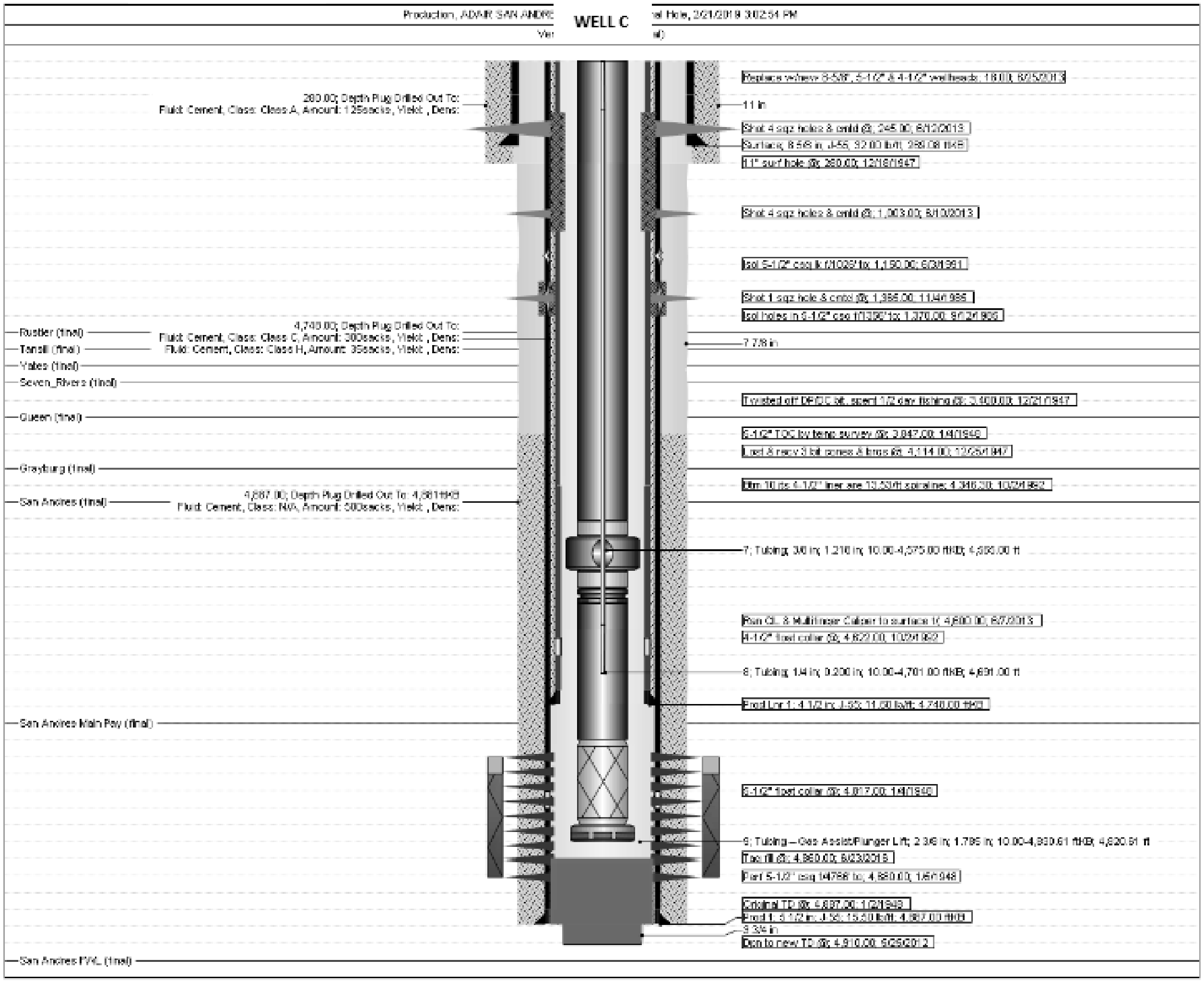

CCAS - SCF / BF / 1000'
10000
1000
100
10
1
0.1
1
22
43
64
85
106
127
148
169
190
211
232
253
274
295
316
337
358
379
400
421
442
463
484
505
526
547
568
589
610
631
652
673
694
715
736
757
778
799
820
841
862
883
904
925
946
Days
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
Min PLGR

Figure 11



WELL C
280.00; Depth Plug Drilled Out To:
Fluid: Cement, Class: Class A, Amount: 125sacks, Yield: , Dens:
11 in
Shot 4 sqz holes & cmtd @; 245.00; 6/12/2013
11" surf hole @; 280.00; 12/16/1947
Shot 4 sqz holes & cmtd @; 1,003.00; 6/10/2013
4,740.00; Depth Plug Drilled Out To:
Fluid: Cement, Class: Class C, Amount: 300sacks, Yield: , Dens:
Fluid: Cement, Class: Class H, Amount: 35sacks, Yield: , Dens:
Rustler (final)
Tansill (final)
Yates (final)
Seven_Rivers (final)
Queen (final)
7 7/8 in
Grayburg (final)
San Andres (final)
4,887.00; Depth Plug Drilled Out To: 4,881ftKB
Fluid: Cement, Class: N/A, Amount: 500sacks, Yield: , Dens:
7; Tubing; 3/8 in; 1.210 in; 10.00-4,575.00 ftKB; 4,565.00 ft
8; Tubing; 1/4 in; 0.200 in; 10.00-4,701.00 ftKB; 4,691.00 ft
San Andres Main Pay (final)
9; Tubing – Gas Assist/Plunger Lift; 2 3/8 in; 1.795 in; 10.00-4,830.61 ftKB; 4,820.61 ft
Original TD @; 4,887.00; 1/2/1948
9 3/4 in
San Andres PWL (final)

Figure 12

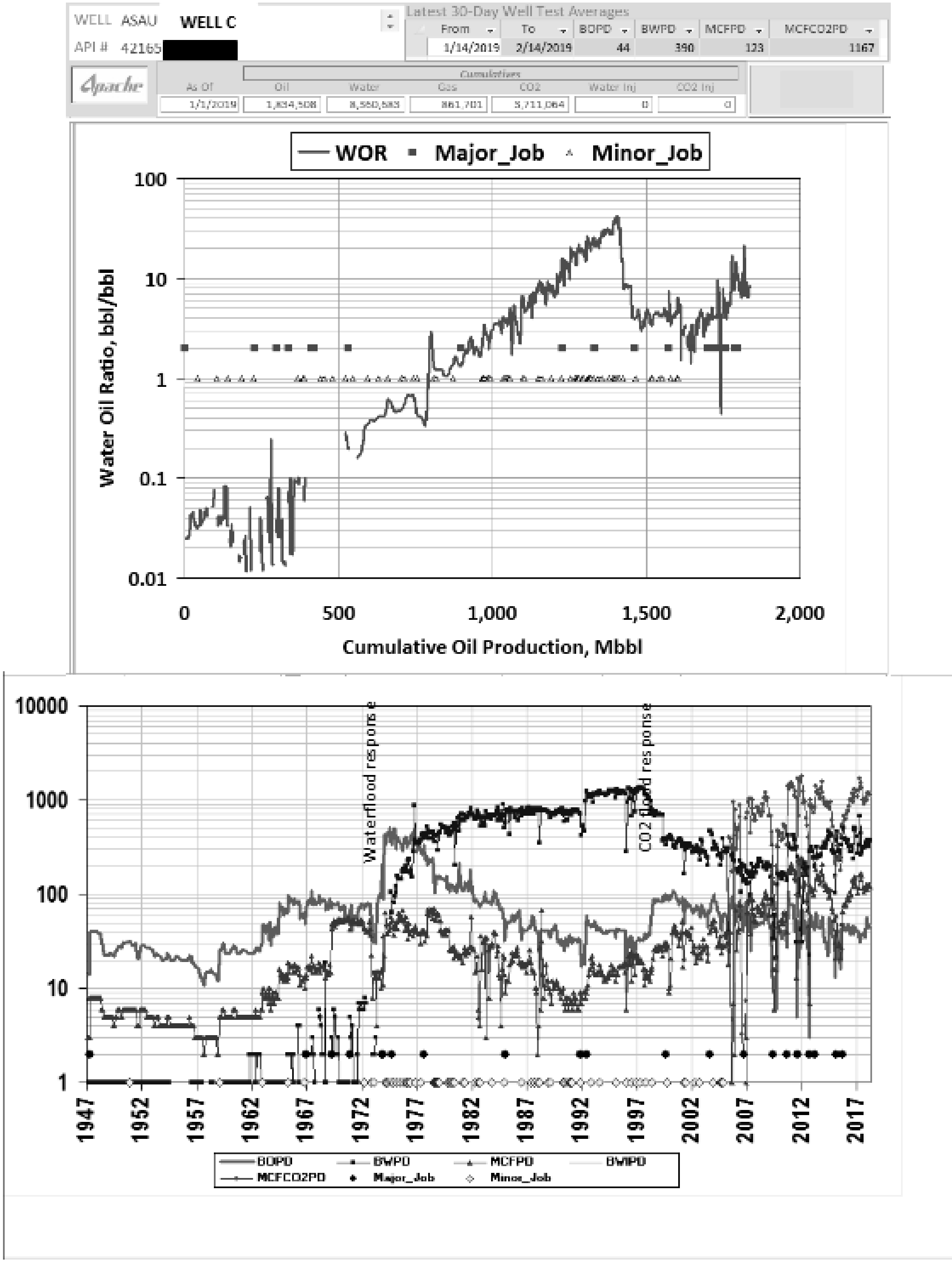

WELL ASAU WELL C
API # 42165[redacted]
Latest 30-Day Well Test Averages
From 1/14/2019
To 2/14/2019
BOPD 44
BWPD 390
MCFPD 123
MCFCO2PD 1167
Cumulatives
As Of 1/1/2019
Oil 1,834,508
Water 8,580,583
Gas 861,701
CO2 3,711,064
Water Inj 0
CO2 Inj 0
WOR
Major_Job
Minor_Job
Water Oil Ratio, bbl/bbl
Cumulative Oil Production, Mbbl
Waterflood response
CO2 flood response
BOPD
BWPD
MCFPD
BWIPD
MCFCO2PD
Major_Job
Minor_Job

Figure 13

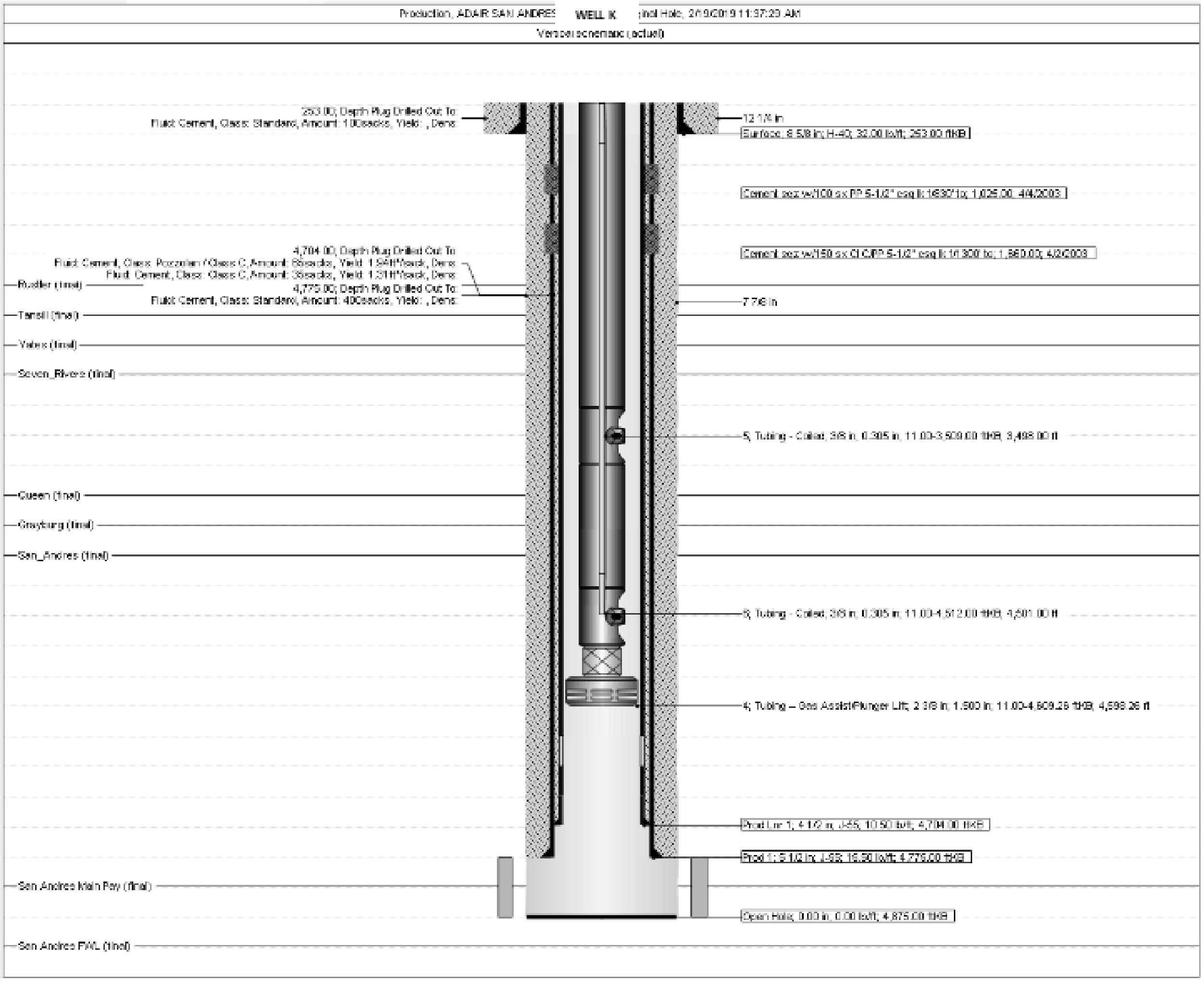
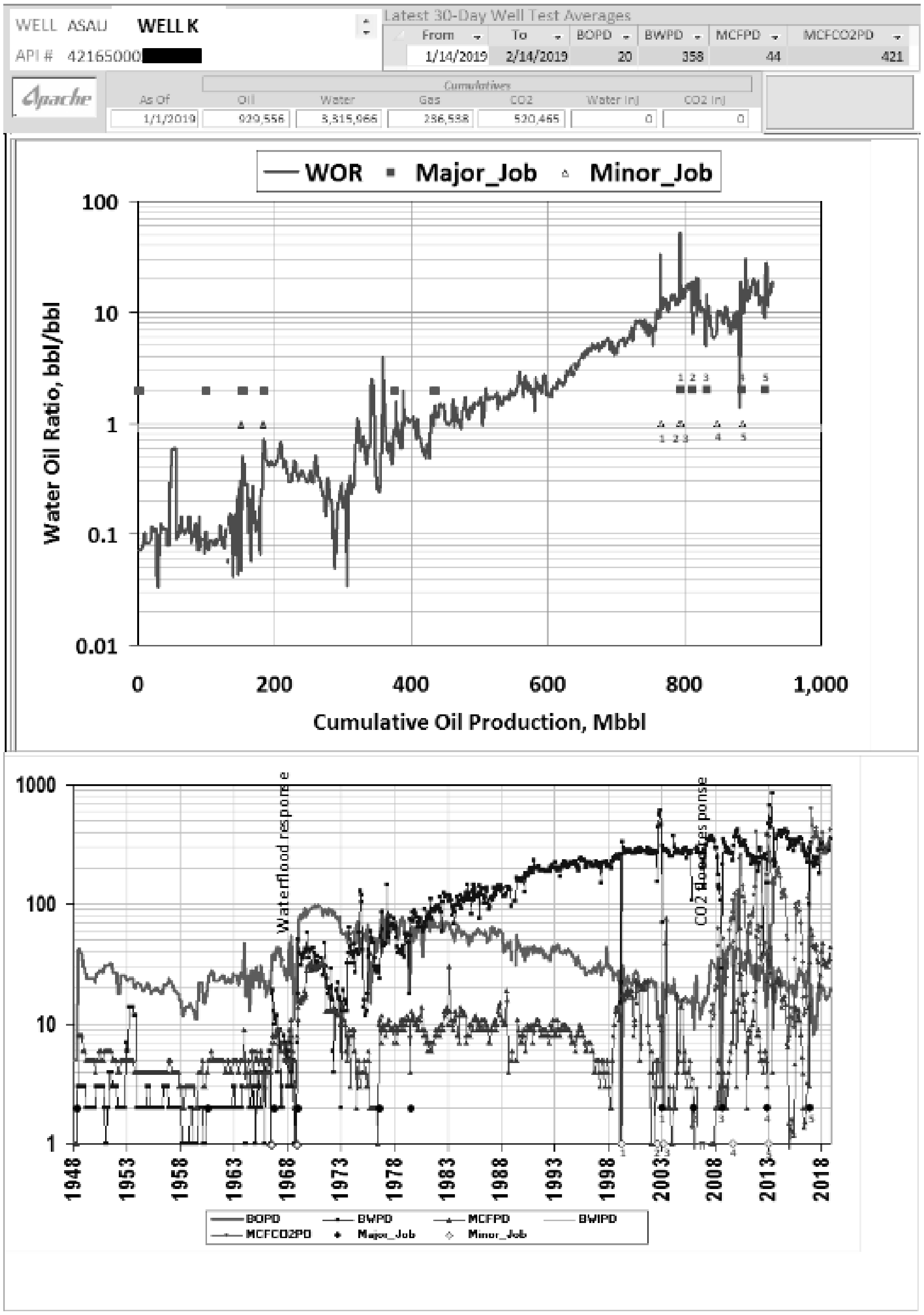

Production, ADAIR SAN ANDRES
WELL K
Original Hole, 2/19/2019 11:37:29 AM
Vertical schematic (actual)
253.00; Depth Plug Drilled Out To:
Fluid: Cement, Class: Standard, Amount: 100sacks, Yield: , Dens:
4,704.00; Depth Plug Drilled Out To:
Fluid: Cement, Class: Pozzolan / Class C, Amount: 85sacks, Yield: 1.94ft³/sack, Dens:
Fluid: Cement, Class: Class C, Amount: 35sacks, Yield: 1.31ft³/sack, Dens:
4,775.00; Depth Plug Drilled Out To:
Fluid: Cement, Class: Standard, Amount: 400sacks, Yield: , Dens:
Rustler (final)
Tansill (final)
Yates (final)
Seven_Rivers (final)
Queen (final)
Grayburg (final)
San_Andres (final)
San Andres Main Pay (final)
San Andres FWL (final)
12 1/4 in
Surface; 8 5/8 in; H-40; 32.00 lb/ft; 253.00 ftKB
Cement sqz w/100 sx PP 5-1/2" csg lk 1630' to; 1,025.00; 4/4/2003
Cement sqz w/150 sx Cl C/PP 5-1/2" csg lk 1/1300' to; 1,860.00; 4/2/2003
7 7/8 in
5; Tubing - Coiled; 3/8 in; 0.305 in; 11.00-3,509.00 ftKB; 3,498.00 ft
Open Hole; 0.00 in; 0.00 lb/ft; 4,875.00 ftKB

Figure 14



- Major
  - 1 – Squeeze 5-1/2” casing leaks
  - 2 – New wellhead / 3 kgal acid
  - 3 – Cement 4-1/2” casing liner
  - 4 – Slickwater frac / KO flwg
  - 5 – CCAS / 3 kgal acid
- Minor
  - 1 – Spot 500 gal White Xylene
  - 2 – ESP repair
  - 3 – Wellhead repair
  - 4 – ESP repair
  - 5 – Dead / new ESP

Figure 15