IMPLEMENTATION OF CYCLIC STEAM STIMULATION TO ENHANCED OIL RECOVERY FOR A SUDANESE OIL FIELD: CASE FULA NORTH EAST FIELD

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Received: 03/11/2018
Accepted: 27/01/2019

ABSTRACT- Tertiary oil recovery or Enhanced Oil Recovery (EOR) is the injection of fluids or energy to the reservoir to improve oil recovery and it can be applied at any phase of oil recovery including primary, secondary, and tertiary recovery and its objective is to increase oil recovery from reservoir depleted by secondary recovery such as water flooding. Steam Injection is to inject steam to heat the oil to higher temperatures and to decrease its viscosity so that it will be more easily to flow; cyclic steam stimulation (CSS) consists of three stages and happened in single well, CSS is particularly attractive because it has quick payout, however, recovery factors are low (10-40%) from Original Oil in Place (OOIP). In a variation, CSS is applied under fracture pressure.

Fula North Field (FNE) reservoirs are highly porous (~30%), permeable (1-2) Darcy and unconsolidated in nature. the fluid properties include viscous crude with 15 to 17.7 API. Corresponding viscosity are in the range of (727 and 3800) cp at reservoir conditions and the current recovery factor is 3.6 %.

The objective of this paper is to illustrate and analyze the performance of CSS phase's implementation starting from the first pilot up to full field scale through different stages.

In this paper overall analysis for the CSS performance implementation including the injection parameters in FNE field will be presented furthermore detail comparison between CSS cycles and cold production discussed. Finally the challenge for this project has been listed; Advanced Thermal EOR Simulator from Computer Modeling Group (CMG) software has been used to propose the location of the new wells and to compare between CSS and Cold case for FNE Field.

The result showed that the CSS is very successful and the average oil rate is almost 1.6 times compared to cold production, the CSS only can increase the recovery percent from 32.5 to 34.2% which makes it more attractive method as development scenario for FNE oil field, and the new wells drilled with 100 % success ration.

Keywords*: EOR, CSS, Full Field Implementation, Sudanese Oil Field*

المستخلص- الاستخلاص الثانوى المعزز (EOR) هو حقن السوائل أو الطاقة في المكمن لتحسين استخلاص النفط ويمكن تطبيقه في أي مرحلة من مراحل انتاج النفط بما في ذلك المرحله الأولية والثانوية و الاستخلاص الثانوى المعزز وهدفه زيادة استخلاص النفط من الخزان المستنفد بواسطة الاستخلاص الثانوي مثل حقن المياه, حقن البخار هو حقن البخار لتسخين الزيت إلى درجات حرارة أعلى ولتقليل اللزوجة بحيث يكون التدفق أكثر سهولة. يتكون التحفيز البخاري الدوري (CSS) من ثلاث مراحل ويتم فينفس البئر ، ال CSSفعال جدا بشكل خاص لأنه يحتوي على دفعات سريعة ، ومع ذلك ، فإن عوامل الاستخلاص منخفضة حوالى (10-40 ٪) من احتياطى النفط في المكمن .(OOIP) في صيغة مختلفة ، يتم تطبيق CSS تحت ضغط الانكسار.

حقول الفوله شمال FNE)) تعتبر ذات مسامية بدرجة كبيرة حوالى (~ 30٪) ، ومساميه عاليه (1-2) دارسي وغير متماسكه في الطبيعة. وتشمل خصائص السوائل الخام اللزج من 15 إلى 17.7 .API اللزوجة (727 و 3800 cp (في ظروف المكمن وعامل الاستخلاص الحالي هو 3.6٪.

يتمثل الهدف من هذه الورقة في توضيح وتحليل أداء مرحلة تصميم CSS بدءًا من المرحلة التجريبية الأولى حتى التطبيق الحقلى الكامل لهذه التجربه خلال المراحل المختلفة.

في هذا البحث سيتم عرض تحليل شامل لتنفيذ أداء CSS بما في ذلك معاملات الحقن في الحقل FNE بالإضافة إلى المقارنة التفصيلية بين دورات CSSوإنتاج الابار البارده التي تمت مناقشتها. وأخيرا سيتم سرد التحديات لهذا المشروع ؛ تم استخدام برنامج كمبيوتربمتطور ومتخصص فى الاستخلاص الثانوى للنفط من برنامج لاقتراح موقع الآبار الجديدة والمقارنة بين بين ابار البخار وابار البارده فى هذا الحقل.

أظهرت النتائج أن CSS كانت ناجحة جداً ومعدل انتاج النفط يعادل 1.6 مرة تقريباً مقارنة بالإنتاج البارد ، ويمكن لـ CSS فقط زيادة معدل الاسترداد من 32.5 إلى 34.2٪ على المدى البعيد مما يجعله أكثر جاذبية كمقترح تطوير حقل الفوله شمال النفطي ، وتم حفر الآبار الجديدة بنسبة نجاح 100٪.

Introduction

Enhanced Oil Recovery (EOR) is a broader idea that refers to the injection of fluids or energy not normally present in an oil reservoir to improve oil recovery that can be applied at any phase of oil recovery including primary, secondary, and tertiary recovery. Thus EOR can be implemented as a tertiary process if it follows a water flooding or an immiscible gas injection, or it may be a secondary process if it follows primary recovery directly.

Various methods of enhanced oil recovery (EOR) are essentially designed to recover oil, commonly described as residual oil, left in the reservoir after both primary and secondary recovery methods have been exploited to their respective economic limits [2].

Increasing of the knowledge and improving the technology is one of the main reasons to attract and encourage the clients and investors to implement the EOR. In addition to most of the easy oil (green fields) is already produced as well as the production reached the peak already more than 10 years ago. As known; Enhanced oil recovery divided into four groups: Chemical, Thermal, Miscible, and Microbial.

Thermal methods have been tested since 1950's, and they are the most advanced among EOR methods, as far as field experience and technology are concerned. They are best suited for heavy oils (10-20° API) and tar sands (≤10° API). Thermal methods supply heat to the reservoir, and vaporize some of the oil. The major mechanisms include a large reduction in viscosity, and hence mobility ratio. Other mechanisms, such as rock and fluid expansion, compaction, steam distillation and visbreaking may also be present. Thermal methods have been highly successful in Canada, USA, Venezuela, Indonesia and other countries [8].

Cyclic steam stimulation is a "single well" process, and consists of three stages. In the initial stage, steam injection is continued for about a month. The well is then shut in for a few days for heat distribution, denoted by soak. Following that, the well is put on production. Oil rate increases quickly to a high rate, and stays at that level for a short time, and declines over several months.

Cycles are repeated when the oil rate becomes uneconomic. Steam-oil ratio is initially 1-2 or lower, and it increases as the number of cycles increase. Near-wellbore geology is important in CSS for heat distribution as well as capture of the mobilized oil. CSS is particularly attractive because it has quick payout, however, recovery factors are low (10-40% OIP). In a variation, CSS is applied under fracture pressure.

Thermal methods are the most commonly used Enhanced Oil Recovery methods around the world; one of them is the cyclic steam stimulation process had been implemented in many Sudanese fields such as, Bamboo Main oil field, Bamboo Main oil field, Hila, Fula Central and FNE oil field and has been consider as the most successful EOR Projects in Sudan.

The objective of this paper is to discuss the result of pilot and CSS phases and stage, full field implementation and comparison between CSS and Cold production will be done, evaluation, challenge and way forward for this field will be presented.

Raj Deo et.all 2011: illustrates the successful design, implementation and evaluation of cyclic steam stimulation pilot in heavy oil field of Sudan. CSS has been implemented in eight selected wells , Actual results are better than predicted in simulation studies Also they discussed improvement in oil production and its variation with formation and fluid characteristics , formation thickness , depth of formations , duration of injection and soaking periods along-with response variables like oil-steam ratio and steam/water production . Operational challenges in preventing the heat losses in annulus, lifting challenges and sand production are also discussed [6].

Wang, Ruifeng et.all 2011: discussed a paper demonstrates the first cyclic steam stimulation (CSS) pilot test in Sudan, which was applied in FNE shallow heavy oil reservoir, CSS Pilot tests on two wells began in 2009. Convincible results have been monitored with well daily rates 3-4 times of cold production wells with low water cut. Another six CSS wells further came on stream from July. 2010, achieving similar positive results, conclusions drawn from pilot test were as follows: 1) Optimized perforation contributed to low water cut; 2) steam injection density was optimized around 120 t/m; 3) Natural gas as heating source greatly reduce operating cost [9].

Eldias Anjar Perdana et.all 2011 provided a case study about CSS in two wells of Melibur field, many experiences were conducted; one of them is the effect to offset well that indicates there is a connection and high heat conductivity between wells. Incremental of initial production rate about 40% occurred in first well. In second well, this operation gives an effect to offset well with the incremental of production rate reach 100% in nearest well. Based on characteristic of formation and oil, Melibur field it is suitable with steam flood method to enhance the oil recovery. Therefore, CSS pilot project is performed to study the impact of steam injection for incremental oil recovery. [4].

Husham and ELamin 2016 provide a feasibility study from screening , design optimization as well as implementation of cyclic steam stimulation (CSS) in BBW 42 as first well in GNPOC in addition to various challenges and recommendations and the result show that the CSS can almost double the production from 280BOPD up to 471 BOPD [5].

All previous papers and studies for FNE Oil Field discussed the pilot designing and implementation while this paper will be the first to illustrate the full field implementation of CSS in FNE Oil Field.

FNE reservoirs are highly porous (~30%), permeable (1000-2000 mD) and unconsolidated in nature. The fluid properties include viscous crude with 15 to 17.7 API. Corresponding viscosities are in the range of 250 cp and 500 cp at reservoir conditions.

Fula North East FNE oil field is located in the Northeast of Fula sub basin, 9 Km from Fula CPF 3 D Area: 72 km^2.3 structure units in oil-bearing area: (FNE-1, FNE-3 & FNE-N), Fig. 1 shows the FNE field location. It has two main Pay Zones are: Aradeiba (d) which has OIIP 33.23 MMSTB and Weak edge water and Bentiu (a, b & c) which has OIIP: 265.5 MMSTB, Massive sand, Burial Depth (460~580 m), and Bottom water support

FNE oil field is consider as heavy oil field and it has shallow reservoir the reservoir properties are in tables (2 &3), at 529 m depth the average pressure is 576 psi and the average temperature is 43.9^0c, FNE has Conventional heavy oil in both Aradaiba & Bentiu and the Reservoir Fluid Properties in table (1).

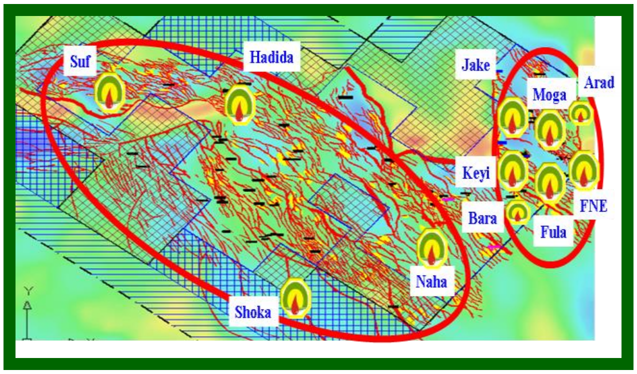

Figure (1): Fula North East FNE Location [1].

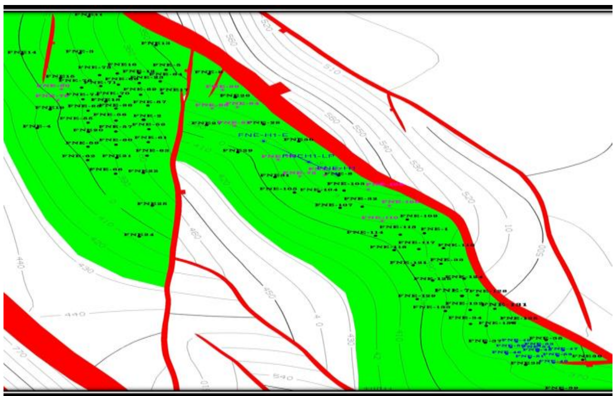

Figure (3): Illustrate the well locations in Bentiu Formation [1].

Materials and Methodology

Materials:-

The Geological data, reservoir data and production data for FNE oil field has been collected and used for analysis to identify the situation of the field and it is suitability for conducting steam injection and full field implementation.

Reservoir Characterization

Table (1): Crude Oil Properties and Water Properties of FNE Oil Field [1].

Crude properties	
API	17.7
TAN(mgKOH/l)	5.4
Pour point(^{0}c)	4
Viscosity @29^{0}c(cp)	3800
Viscosity @50^{0}c(cp)	727.33
Water properties	
Water type	$NaHCO_3$
PH value	7.64
Salinity (mg/L)	1067.82
Chloride content (mg/L)	524.66

Table (2): Reservoir Characterization of FNE oil field [1].

Formation	Aradaiba	Bentiu
Φ(%)	25 to 30	29 to 34
K(md)	100 to 5000	1000 to 10000
Net pay	3.3	31.5

Steam Injection Parameters

1. Injection rate: 8 -10 t/h
2. Injection Intensity:132 t/m.
3. Total amount: ton. 1518 ton
4. Steam quality at wellhead: >75%.
5. Steam quality at well bore : >55%.
6. Steam Injection Pressure of wellhead : <1378Psi.
7. Fracture Pressure gradient: 285.56 Psi/100m.
8. Formation Fracturing Pressure: 1453.0 -1504 Psi.

Advanced Thermal EOR Simulator from Computer Modeling Group (CMG) software has been used to propose the location of the new wells and to compare between CSS and Cold case for FNE Oil Field.

Methods:-

- Date Collection
- Review data
- Build simulation Model
- Compare between CSS and Cold wells
- Propose new wells
- Analysis the performance for FNE wells
- List the CSS challenges in FNE fields.

Results and Discussion

FNE oil field is heavy oil field and has very large Original Oil in Place about 298 MM STB and up 2016 only 10 MM STB has been produced Fig. (3) and the recovery factor in only 3.6 %, that why the thermal recovery is essential for this field and the first pilot has been conducted in FNE-16 well and the results shown that the CSS can produce double the production and then additional wells have been added at each phase, Up to 2016 the total CSS wells reach to 67 wells including 37 wells under the first and second cycle, 24 wells under the third and fourth cycle, 6 wells under the fifth cycle.

Table (3):-OOIP & Reserve Status (Elbaloula, H. 2015)

Item	CHOPS	Thermal	Total
OOIP (MMSTB)	298.73	298.7	298.7
EUR (MMSTB)	56	137	137
NP (MMSTB)	3.21	7.54	10.75
Remaining EUR	52.41	131.9	126.3
Up to Date EUR	6.41	3.74	6.36
Expected RF %	18.9	45.96	45.96
Up to Date RF %	1.07	2.52	3.60

Figure (3):- OOIP, Reserve and Cum. Production for FNE (Elbaloula, H. 2015)

Steam injection temperature of 270 ºC, with 5~7 MPa injection pressure, steam injection quality of more than 0.6, and steam injection rate of 192t/h ; were used as steam injection parameters for all cycles while additional 10% of steam volume is added when changing from cycle to another.

The Advanced Thermal EOR Simulator from Computer Modeling Group (CMG) software called STARS has been used to propose 49 well for the duration between 2014 up 2016 and all the wells drilled with 100 % successful ratio Fig. (4 & 5) shows the porosity and permeability distribution in 3D view and the location of the new drilled wells in FNE oil field from simulation model and in the structure map can be shown in Fig. (3).

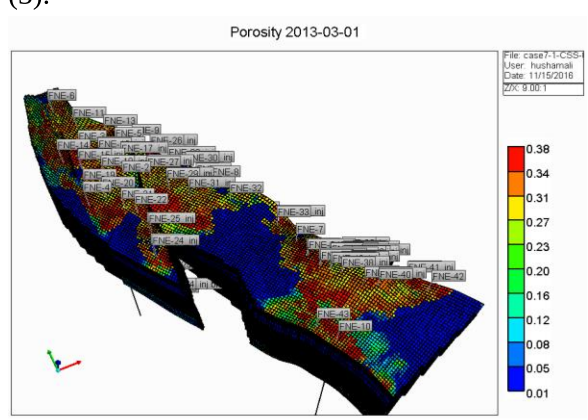

Figure (4): 3D view of Porosity distribution and wells location as of 2013 in FNE Oil field

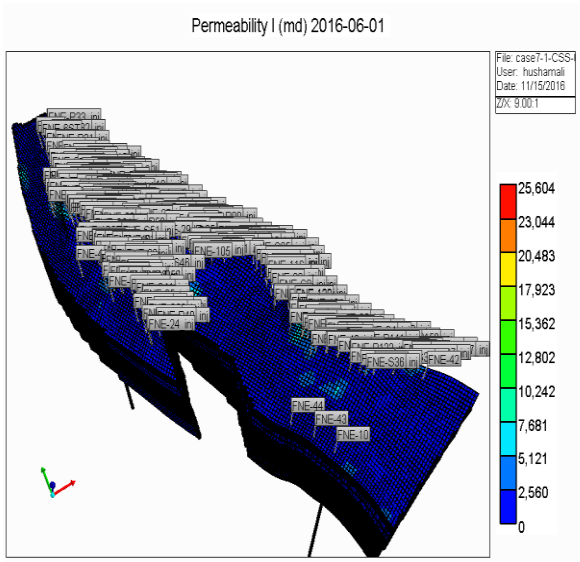

Figure (5): 3D view of Permeability distribution and wells location as of 2016 in FNE Oil field

FNE Production Summery

As of Dec. 2015 Total number of wells are 79 including 58 wells are CSS and the CHOPS wells are 21, the Daily average Oil Rate is 5,938 STB/D for CSS and 1,070 STB/D for CHOPS wells, and the average Total Oil Rate is 7008 STB/D, the average Oil Rate for Single CSS well is 126 STB/D and 65 STB/D for CHOPS well, for the water Cut the Total is 43%, 46% for CSS wells and CHOPS is 29%.

The CSS Well Status in FNE oil field currently there are 58 CSS well in this fields including 6 well s Under 5th Cycle, 14 Under 4th Cycle, 10 wells Under 3th Cycle, 2 wells Under 2nd Cycle and 26 wells Under 1st Cycle.

First Pilot in FNE Oil Field

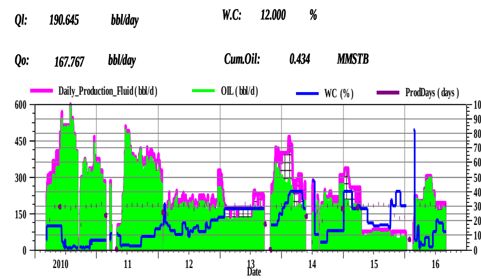

Figure (6): FNE-16 Production Performance [1].

The pilot has been started by phase #1 which is four well; the first well is FNE -16 in Fig. (6) And after CSS evaluation the result shown that the production has been increased from 100 to almost average 300 bbl/d and the peak reached up to 600 bbl./d and the CSS extend to another pilot area.

Comparison between CSS and Cold

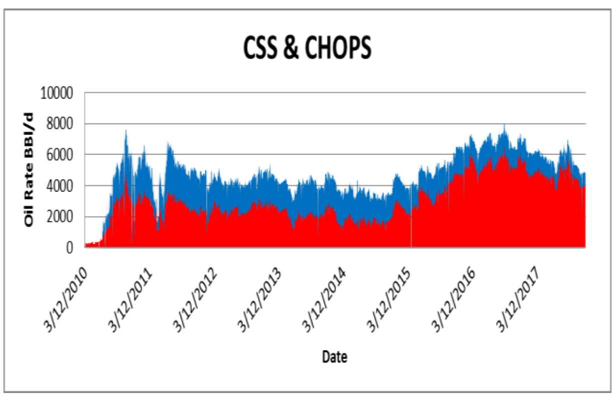

Figure (7): CSS & CHOPS Production in FNE field.

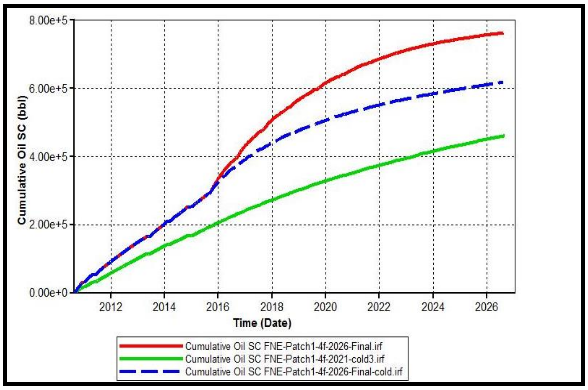

Figure (8): Comparison between CSS and Cold [1].

The actual production of CHOPS and CSS wells can be found in Fig. (7) and it's clear that the CSS wells produce more than CHOPS wells , When it been compared between CSS and Cold in Fig. (8) which shows a comparison between CSS and Cold case using the advanced thermal simulation it has been found that the difference between CSS and Cold Heavy Oil Production with Sand (CHOPS) is 2.55 MMBBL which is almost 1.6 times if the field continue to produce by cold only 24 % can be produced but the CSS can increase the recovery factor up to 34%, Fig. (9) And table (4) shows the analysis for FNE-25 as example to compare between CSS and Cold production.

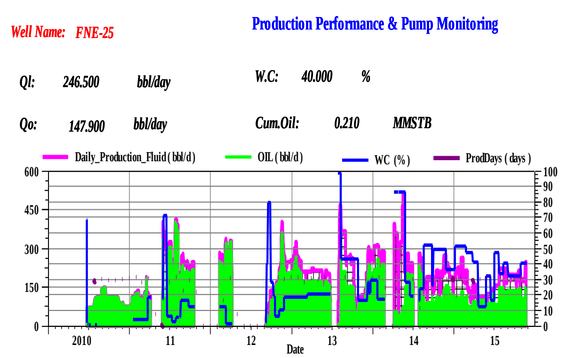

Figure (9): FNE-25 Production Performance [1].

Table (4): FNE-25 Production Performance and Summery for each Cycle

Cycle #	Startup Date	End Date	Duration (Days)	Uptime (Days)	Uptime (%)	Peak Oil Rate (BOPD)	Avg. Oil Rate (BOPD)	Cum. Oil (STB)
CHOPS	25-Jun-2010	9-Apr-2011	289	279	96%	181	98	27,199
1	1-Jun-2011	8-Apr-2012	313	186	59%	400	235	43,754
2	10-Sep-2012	25-Jun-2013	289	286	99%	361	169	48,411
3	30-Jul-2013	31-Aug-2013	33	33	100%	265	128	4,225

CSS Performance Summary

When we compare the performance of the Cold wells and the CSS in the same well it has been found that the production increased to almost double for the first cycle and 70% for second and 50 % in the third cycle and the production returned to be same as cold after the fourth cycle for most wells (Fig. 10&11 and table 5).

Table (5): Comparison between CHOPS and different Cycles

Cycle #	Injected Steam Amount (bbl)	Avg. Soaking Time (Days)	Cumulative Oil Production (STB)	Cumulative Water Production (bbl)	Avg. Cycle Duration (Days)	Avg. Uptime (%)	Avg. Oil Rate (STBPD)	Oil/Steam Ratio
CHOPS	--	--	264,006	21,346	309	94	121	--
1	457,470	33	2,830,254	526,414	370	86	211	6.2
2	373,217	19	1,302,752	465,189	268	91	169	3.5
3	406,378	18	1,030,439	782,467	297	96	129	2.5
4	214,618	19	658,455	354,905	302	95	123	3.1
5	54,159	14	47,376	34,982	355	99	172	0.9

The average oil daily production is 319 bbl. /d for the first cycle and decreased to 256, 249 and 151 for the second, third and fourth cycles respectively Fig (10) and this consider as normal reduction for CSS well performance.

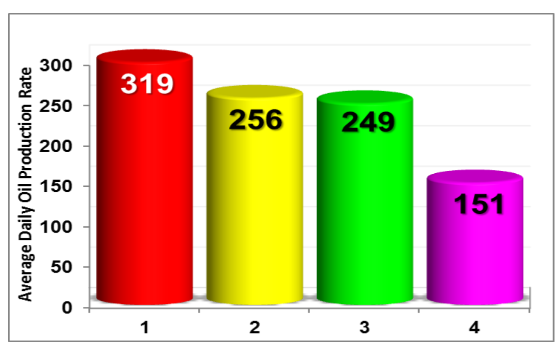

Figure (10): The average oil daily production for each Cycle

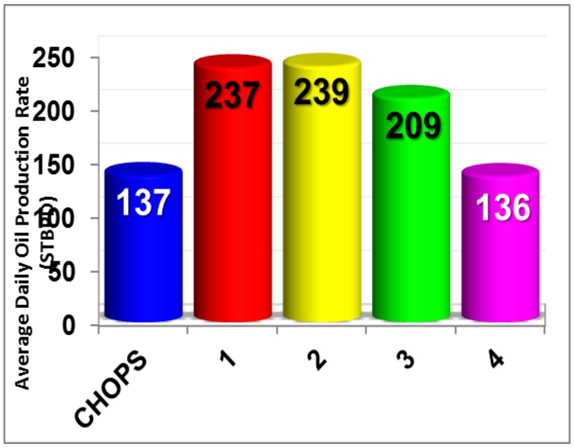

Figure (11): Comparison between CHOPS and CSS Cycles for all wells

Summery for the CSS Phases and stages

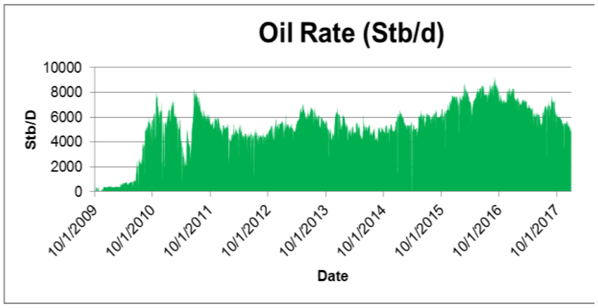

Figure (12): FNE Total Production Profile [1].

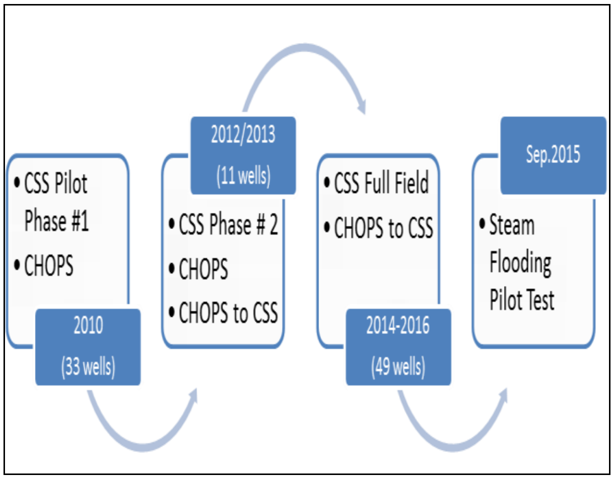

Figure (13): CSS Phases and Stages

The first pilot phase 31 wells by 2010 to 2012 from 2012 to 2013 11 wells has been added and then 49 wells has drilled as CSS wells from 2014 to 2016. The average oil daily production for this field has been increase from 5,300 bbl/d as of Dec. 2014 to 8,300 bbl/d as of Sep., 2016 the peak production has recorded on 2016 as 9000 bbl/d.

Fig. (12) Shows the CSS Phases and Stages for FNE Field starting from 2010 and describing the change from pilot to full field and from CSS to Steam flooding at this field.

Way Forward for FNE Oil Field

After the successful implementation of CSS as full field in FNE Oil Field the plan is to go steam flooding and a pilot has been started since September, 2015 and still under evaluation, the Fig (13) shows the suggested way forward for this field considering the CSS and SF scenarios.

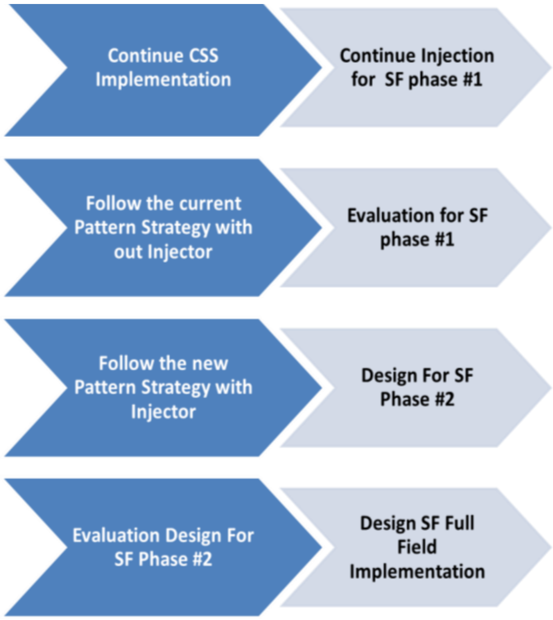

Figure (14): The Suggested Way Forward for FNE Oil field

Conclusions

Implementation of Cyclic Steam Stimulation to Enhanced Oil Recovery for Fula North East Field has been reviewed and discussed.

FNE Oil field has big OOIP of s 298.73 MMSTB and up to date the recovery factor is only 3.6%, accordingly more thermal activity and wells is required to improve the recovery factor.

FNE Production Summery has been analyzed and the current daily average oil production rate is 8,000 STBPD (CSS: 130 STBPD/Well, CHOPS: 65 STBPD/well).

Current available wells: 79 (58CSS + 21 CHOPS), always there are 5~6 wells shut-in for CSS operations Most of the current CSS wells are undergoing 3rd & 4th cycles.

Comparison between CSS and CHOPS has been done and form simulation study the difference between CSS and CHOPS is 2.55 MMBBL which is almost 1.6 times.

The result showed that the CSS is very successful and the average oil rate is almost 1.6 times compared to cold production, the CSS only can increase the recovery percent from 32.5 - 34.2% which makes it more attractive method as development scenario for FNE oil field.

Recommendation

To optimize the CSS parameters and timing for next cycle should be done to get high recovery factor.

It highly recommended Convert the CHOPS Wells to CSS by (using of N2 assisted with CSS, Convert to producer in SF Stage).

After the successful implementation of CSS as full field in FNE Oil Field its highly recommended to go for steam flooding stage.

Nomenclature

API	***American Petroleum Institute***
Bbl. /d	***Barrel per Day***
BOBP	Barrel Oil per Day
CHOPS	Cold Heavy Oil Production with Sand
CP	Centipoise
CMG	Computer Modeling Group
CSS	Cyclic Steam Stimulation
EOR	Enhanced Oil Recovery
EUR	Estimated Ultimate Recovery
FNE	Fula North East
IOR	Improved Oil Recovery
M	Meters
MMSTB	Million Stock Tank Barrel
NP	Cumulative Production
OEPA	Oil Exploration and Production Authority
OOIP	Original Oil in Place
RF	Recovery Factor
SF	Steam Flooding
STB/D	Stock Tank barrel per day
STOIIP	Stock Tank Oil Initial In Place
%	Percent
O C	Degree Celsius

Acknowledgements

The authors would like to thank Oil Exploration and Production Authority (OEPA), Ministry of Petroleum and Sudan University of Science and Technology for the permission to publish this paper.

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