The Challenges of Cyclic Steam Stimulation (CSS) to Enhanced Oil Recovery (EOR) in Sudanese Oil Field

Husham A. Elbaloula
Sudan University of Science and Technology, Petro-Energy-E&P
PDOC & PE Tower, Khartoum, Sudan
hushamali66@gmail.com, hushamali@petroenergy-ep.com

Dr. Tagwa A. Musa
College of Petroleum Engineering & Technology
Sudan University of Science and Technology
Khartoum, Sudan
tagwam@gmail.com

Abstract

More than two-thirds of oil discovered around the world still remains unrecovered, 40 – 70% of the original oil is still left in place after using the conventional production technique, namely, primary and secondary recovery techniques (J.A. Boon, 1984).

The world demand for petroleum has been steadily on the increase with the International Energy Agency (IEA) projecting that the world petroleum consumption will rise from 3564 MTOE in 2007 to as much 5471 MTOE in 2015 and 6301 MTOE in 2030.

Implementation of EOR methods is a must for maximizing production and recovery from Sudan's oil fields. These methods must be studied carefully to assure proper selection and implementation.

There are Six EOR Projects in Sudanese Oil Fields Namely Three Thermal EOR (two CSS and one steam flooding) and two chemical EOR projects and one gas/N2 injection projects, the thermal projects are under implementation phase meanwhile the other Chemical /Gas projects are under Designing and Evaluation.

In this Paper there will be an overview of Thermal EOR Projects in Sudanese Oil Fields, illustrate and analyze the CSS Concerns and Challenges in Sudanese oil fields such as Depth limitation (more than 1400m), Conventional completion wells, Comingle Injection & Production.

The Result show that the thermal EOR projects are very successful and almost gave double production from 130 bbl/day to 300 bbl/day in FNE Oil Field and from 280 bbl/day to 440 bbl/day in Bamboo Oil Field.

In order to get maximum recovery from the wells it's highly recommended to select shallow depth, thermal completion and to avoid comingle layer injection or to use special technique for separate layer injection.

Keywords

EOR, CSS, Challenges, Sudanese Oil Field.

Introduction

More than two-thirds of oil discovered around the world still remains unrecovered, 40 – 70% of the original oil is still left in place after using the conventional production technique, namely, primary and secondary recovery techniques (J.A. Boon, 1984).

The world demand for petroleum has been steadily on the increase with the International Energy Agency (IEA) projecting that the world petroleum consumption will rise from 3564 MTOE in 2007 to as much 5471 MTOE in 2015 and 6301 MTOE in 2030.

Nearly 2.0 × 10^{12} barrels (0.3 × 10^{12} m3) of conventional oil and 5.0 × 10^{12} barrels (0.8 × 10^{12} m3) of heavy oil will remain in reservoirs worldwide after conventional recovery methods have been exhausted. Much of this oil would be recovered by Enhanced Oil Recovery (EOR) methods, which are part of the general scheme of Improved Oil Recovery (IOR) The choice of the method and the expected recovery depends on many considerations, economic as well as technological.(Thomas, 2008).

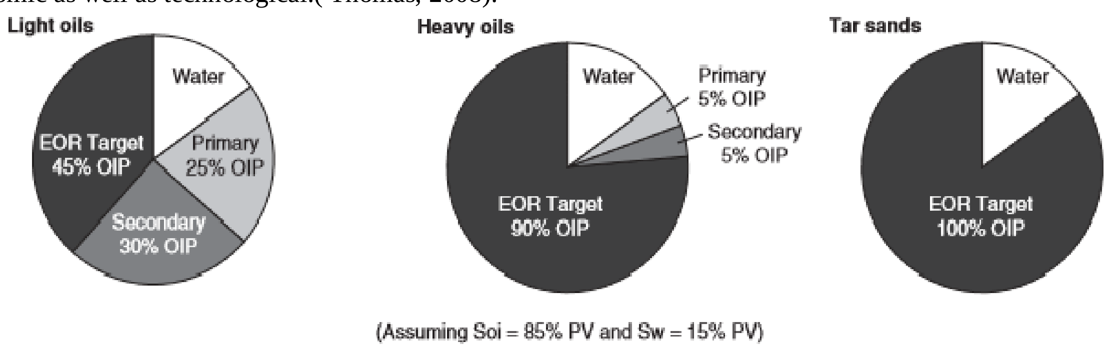


Figure (1):EOR target for different hydrocarbons.(Thomas 2008).

Many EOR methods have been used in the past, with varying degrees of success, for the recovery of light and heavy oils,as well as tar sands. Thermal methods are primarily intended for heavy oils. (Thomas 2008).

Considering high viscosity of heavy oil, thermal recovery methods seem the right solution for development of shallow heavy oil fields

Enhanced Oil Recovery (EOR)

Tertiary oil recovery (enhanced oil recovery EOR) its objective is to increase oil recovery from reservoir depleted by secondary recovery it has three major categories will be discussed .First was stimulated in response to oil Embargo 1973 and flowing energy , the period of high activity lasted until the collapse of worldwide oil pieces in 1986 over years interest in EOR has been tempered by the increase in oil reserve and production , , the discovery of major oil filed in North slop of Alaska ,North sea and other region added large volume of oil to the worldwide market , Although large volume of oil remain in mature reservoir ,the oil will not be produced in large quantities by EOR process unless these process can compete economically with the cost to oil production from conventional sources , thus as reservoir age dichotomy exists between desire to pressure well for potential EOR process and lack of economic incentive .(Green and Willhite ,1998).

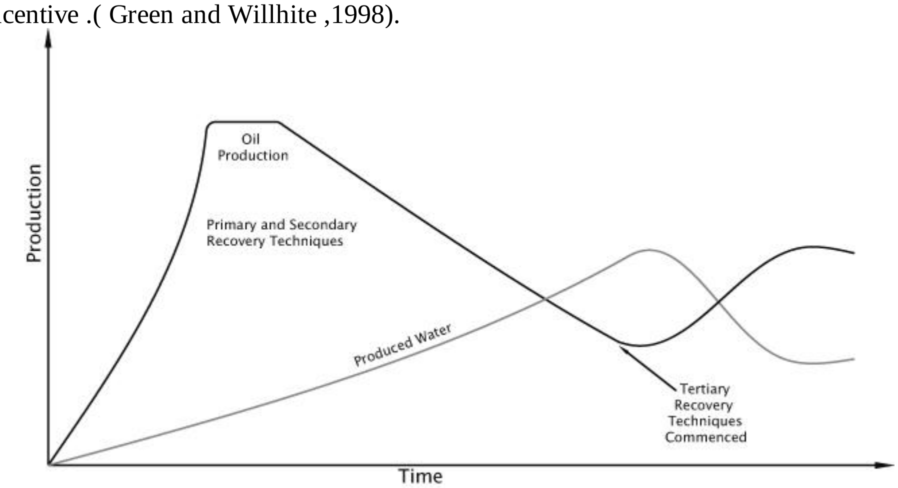


Figure (2): Stages of Recovery. (Green and Willhite ,1998).

Thermal EOR:

Thermal recovery processes rely on the use of thermal energy in some from both to increase the reservoir temperature, thereby reducing oil viscosity by mean of heat and also provide the force to increase the flow rates of the oil to the production well that is why thermal drives .in the thermal stimulation techniques, only the reservoir near the production well is heated.

Stimulation techniques can also be combined with thermal drive ,and in this case the driving force are both natural and imposed ,most thermal oil production is the result of cyclic steam injection and steam drive.(Green and Willhite,1998).

Thermal Processes:

Thermal processes is heated the reservoir to reduce the viscosity of oil or vaporize the oil to make it more mobile and more effectively to recover. Thermal processes provide pressure to move the oil to producing wells (Speight, 2009).

Thermal recovery methods:

i. Cycle steam stimulation (CSS).
ii. Steam drive (steam flooding).
iii. Hot water flooding.
iv. In situ combustion.

Table (1) Classification of EOR Processes (S.M FAROUQ ALI…et al, 1996)

		Oil Properties			Reservoir Characteristics					
Detail Table in Ref. 16	EOR Method	Gravity (°API)	Viscosity (cp)	Composition	Oil Saturation (% PV)	Formation Type	Net Thickness (ft)	Average Permeability (md)	Depth (ft)	Temperature (°F)
Gas Injection Methods (Miscible)										
1	Nitrogen and flue gas	>35↗48↗	<0.4↘0.2↘	High percent of C_1 to C_7	>40↗75↗	Sandstone or carbonate	Thin unless dipping	NC	>6,000	NC
2	Hydrocarbon	>23↗41↗	<3↘0.5↘	High percent of C_2 to C_7	>30↗80↗	Sandstone or carbonate	Thin unless dipping	NC	>4,000	NC
3	CO_2	>22↗36↗ [a]	<10↘1.5↘	High percent of C_5 to C_{12}	>20↗55↗	Sandstone or carbonate	Wide range	NC	>2,500[a]	NC
1–3	Immiscible gases	>12	<600	NC	>35↗70↗	NC	NC if dipping and/or good vertical permeability	NC	>1,800	NC
(Enhanced) Waterflooding										
4	Micellar/ Polymer, ASP, and Alkaline Flooding	>20↗35↗	<35↘13↘	Light, intermediate, some organic acids for alkaline floods	>35↗53↗	Sandstone preferred	NC	>10↗450↗	>9,000↘3,250	>200↘80
5	Polymer Flooding	>15	<150, >10	NC	>50↗80↗	Sandstone preferred	NC	>10↗800↗ [b]	<9,000	>200↘140
Thermal/Mechanical										
6	Combustion	>10↗16→?	<5,000 ↓ 1,200	Some asphaltic components	>50↗72↗	High-porosity sand/ sandstone	>10	>50 [c]	<11,500↘3,500	>100↗135
7	Steam	>8 to 13.5→?	<200,000 ↓ 4,700	NC	>40↗66↗	High-porosity sand/ sandstone	>20	>200↗2,540↗ [d]	<4,500↘1,500	NC
—	Surface mining	7 to 11	Zero cold flow	NC	>8 wt% sand	Mineable tar sand	>10 [e]	NC	>3:1 overburden to sand ratio	NC

From above table (1) the critical screening parameters are (Viscosity and depth).

Cyclic Steam Injection:

The role of steam is to heat oil throughout the reservoir to make it mobile. In the second, the role of steam is to increase the production rate by reducing the near-well bore flow resistance. In both cases, the effect of steam injection decreases as the heated region cools, and it becomes necessary to repeat the injection cycle. Also, in both

cases, subsequent cycles become less effective. In general reservoir heating it is necessary for successive cycles to heat the reservoir which is more and more remote from the production well.(Roger M. Butler1991).
Although the idea of heating reservoir data back more than 100 years , large scale steam drive project began in heavy oil field in the US in early 1950 and were flowed by project in Netherlands and Venezuela , a relative of steam drive is Cyclic steam injection also called steam soak or huff and puff , it was discovered accidentally in 1960 during Venezuela recovery project , Cyclic steam injection recovery uses as single well for both injection and production , steam is injected into well for several days to month or more , the soak period ,after this , the well produced and repeated , the steam heats the rock and fluid surround the wellbore and also provide some drive pressure , by time the steam condensate and oil water produced .(Larry W. Lake 1992)

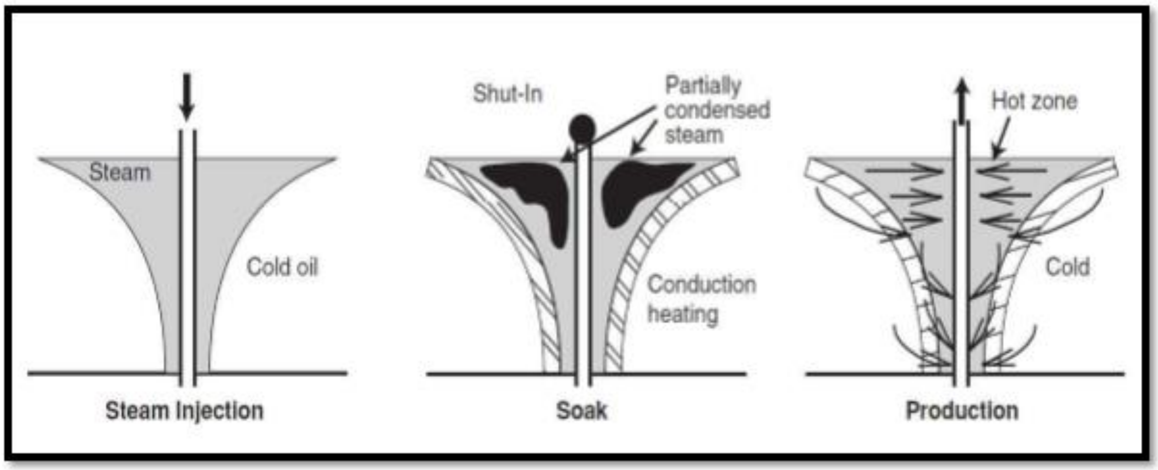


Figure (3) : Cyclic Steam Stimulation (CSS) (S Thomas, 2008)

Steam soak was discovered as a promising production method rather accidentally in 1969, during early steam drive testing in the Mene Grande Tar Sands, When steam erupted at the surface due to breakdown of the overburden, the injection wells were back lowed to relieve the reservoir pressure. This resulted in high oil production rates, all the more impressive because the reservoir is un producible by primary means. It was concluded that injection of limited amounts of steam might be a very effective method for stimulation of heavy-oil wells. (Haan, Lookeren, 1969)

Introduction to Case Study:

Tow case studies in two different companies will be discussed in this paper

Fula North East (FNE) Oilfield is geographically located in the southwest of Sudan, about 700 km from the capital, Khartoum; structurally located in the northeast of Fula sub-basin of Muglad basin and in the southwest of the Moga Oilfield.

FNE Oilfield exploration began in 1989, the first well FNE-1 has been drilled In 2005, it was found one of the largest heavy oil fields in Petroenrgy (PE) block 6 Area.

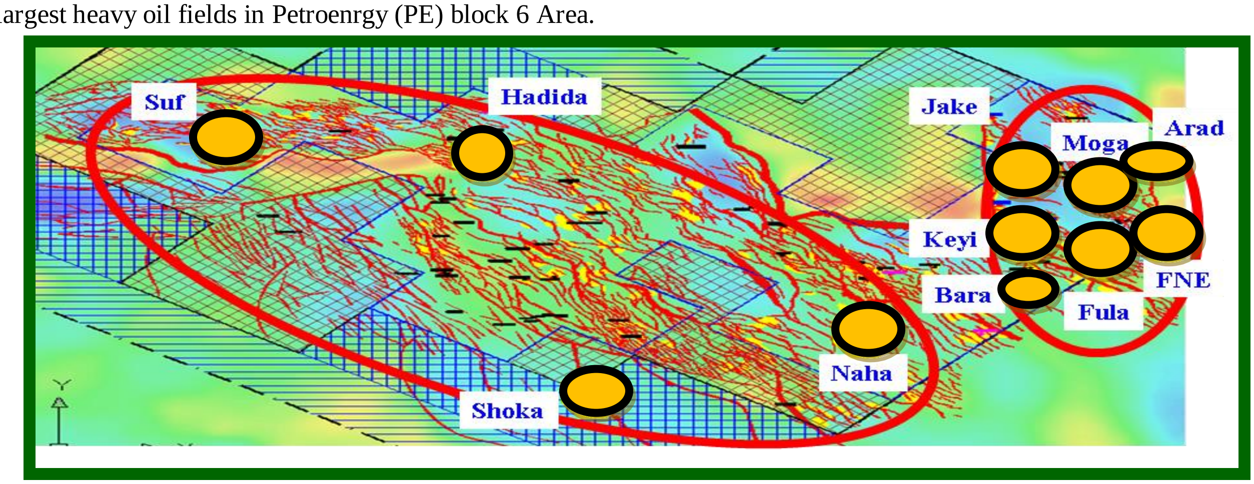


Figure (4): Maglad Basin Block 6.

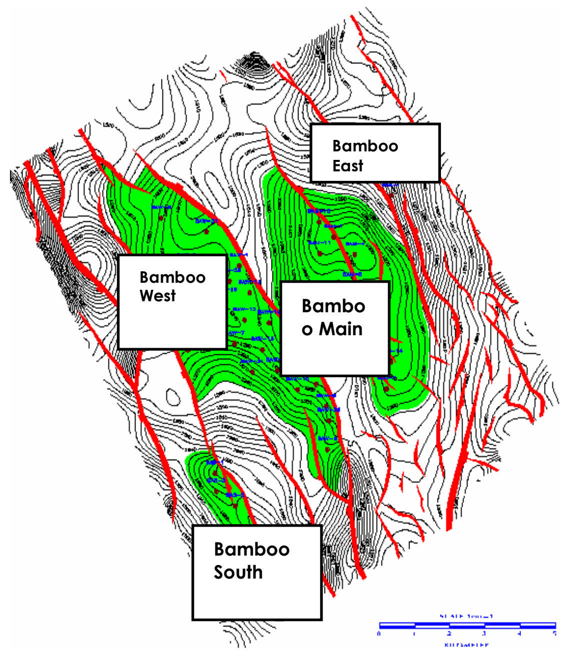
Introduction of Bamboo Oil Field.

Bamboo Oil Field is divided to four sub fields as follow: -

- ✓ Bamboo Main field discovered in 1982 by (Chevron).
- ✓ Bamboo West discovered in Dec.1997 followed by
- ✓ Bamboo South in Feb.2000
- ✓ Bamboo East in Sept.2000 (GNPOC).

The 1st oil production commenced in July 2001, Main producing sand is from Bentiu-1, Bentiu 2 & 3.

Parameters	Bamboo
Reservoir	Bentiu1-3
Top depth, mKB	1200-1450
Initial Res. pressure, psi	2300-4000
Temperature, degC	60-70
Porosity, fraction	0.23
Permeability, mD	300-7000
Oil gravity, deg API	20-12.5
Viscosity, cp	250-3000



Literature Review

In 2016 alali, y etc. discussed study for completion plan for steam flood pilot,] The development of the viscous oil resources of Kuwait is considered a very important strategic goal of the country. The first phase of development plans is under implementation to meet a target production of 60 M bopd by a combination of cold flow and cyclic steam stimulation (CSS) followed by steam flood to have optimum recovery from this resource. The reservoir appears to be a layered one with pay zones varying in fluid and rock property. The 4 pay zones are seen in the Northern part of the field (Fig-), namely Zone-IA, Zone-IB, Zone- IIA and Zone-IIB: .(Alali, Y, etc,2016)

In 2012 Daniel Higuera, et provides study about optimization of cyclic steam stimulation in highly stratified oil reservoir of middle magdalena basin: moriche field. Moriche is a heavy oil field operated by Mansarovar Energy Colombia Limited (MECL), The Oil-Steam ratio (OSR) was less than 1 Bbl / MMBTU which was not economically feasible for the exploitation of the Moriche Field using CSS as a method of recovery (Daniel,2012)

delamaide, Eric in 2017 reviewed both steam injection and polymer flood in light of fundamentals and field experience, Results show that while steam injection can achieve much higher recovery than polymer flood and is also applicable in much higher oil viscosity, polymer flooding is not limited by depth or reservoir thickness ,it has lower operating costs and is also less capital intensive. Thus, there is a large opportunity to develop heavy oil reservoirs using polymer where steam injection is not possible(Delamaide, Eric,2017).

in 2016 studied actual field performances for each formation showing the cyclic steam injection stage and the timing of conversion to continuous steam strategy. A lot of factors will be presented for the steam cycle stage including: voidage replacement ratio (VRR), steam to oil ration (SOR), and the injectivity index performance from cycle to cycle. Then the conversion time from cyclic to continuous steam flooding will be discussed per each area (Basta, George Soliman,2016).

Korany, S. K. In 2015 described a case study of cyclic group steaming of wells (CGSW) in a heavy oil (10-12 API) field located in Egypt(Issaran), During cyclic steam injection in the pilot, a negative effect was noticed during steam injection in some wells on surrounding wells; the gross production rate increased accompanied by an increase in water cut and wellhead temperature leading to loss in oil production, CGSW was implemented by applying steam cycles in all the producers of the pilots simultaneously, allowing for a better distribution of heat around all the wells.result are shown with full description .(Korany, S. K,2015)

In 2012 dennis has estimated The number of enhanced oil recovery (EOR) projects in the middle east (ME) has increased over the past decade, there are 11 EOR projects kicked off, on pilot, or at commercial scale in the ME.Oman is taking the lead in the implementation of EOR projects because of its declining oil production. The urgency of EOR implementation in the ME is a function of declining oil production rates, availability of remaining "easy oil," impending momentum to contain co2 (starting early with the long lead times for such projects), and other geopolitical factors. (dennis denney,2012).

In cold lake in Alberta, Canada in April 1970 the recovery factor was 20% with a well production rate of 80 bbl/day over an average of 6 years. (Sheng, 2013).

Gudao field in china the CSS starting in 4 to 27 August 1991 , the intial oil rate was 23.5 tons/day.(Sheng, 2013).

Wu Yongbin, 2010 studied the effect of applying Superheated Steam Injection in Shallow Heavy Oil Reservoir in North KHAZKHSTAN oil field and the results shows that the average cyclic oil production in cyclic superheated stimulation is 61.73% higher than that in cyclic wet steam stimulation for the previous cycles, and the average water cut is reduced for more than 10% . (Yongbin, et al., 2010)

Also Anna Wegis, 2001 studied the effect of Multi-Zone Injection by Limited-Entry Through Tubing and result shows that these strategy is more effective, economical, and environmentally safe answer than multi-zone injection by limited entry through casing. (Wegis,2001)

The Ondeh field is located in the north east of Syria , its contains 5.1 billion bbls of 12-16 API crude oil and the primary recovery factors is estimated to be only 5 to 7% of the original oil in place. low steam quality at the bottom of the well proved to be the most prominent challenge duo to a combination of heat loss in the wellbore and relatively low steam injectivity , injection into tubing improved steam quality.(minglin li,2010)

Case Studies in Sudan:

CSS have been implemented in SUDAN since 2009 in FNE oil field as first field, the field contain heavy oil in multiple reservoir of Bintiu formation in 8 selected wells spread over the field and its leaded to maximize the recovery factor , the actual result is better than predicted in simulation studies with lower steam intensity of 120 m/m compared to planned 160 m/m. (Abdalla, et al, 2011)

Also Husham Elbaloula , 2016 studied the Designing and Implementation of the First Steam Flooding Pilot Test in SUDANESE Oil Field and Africa and the result showed that converting of Cyclic Steam Stimulation (CSS) to steam flooding after the third cycle could improve the recovery factor of the field up to 43 ~ 50.1%, while CSS only can increase the recovery percent of the suggested well groups by 32.5 - 34.2% of the studied sector model which makes it more attractive method as development scenario for FNE oil field. (Elbaloula, et al,2016).

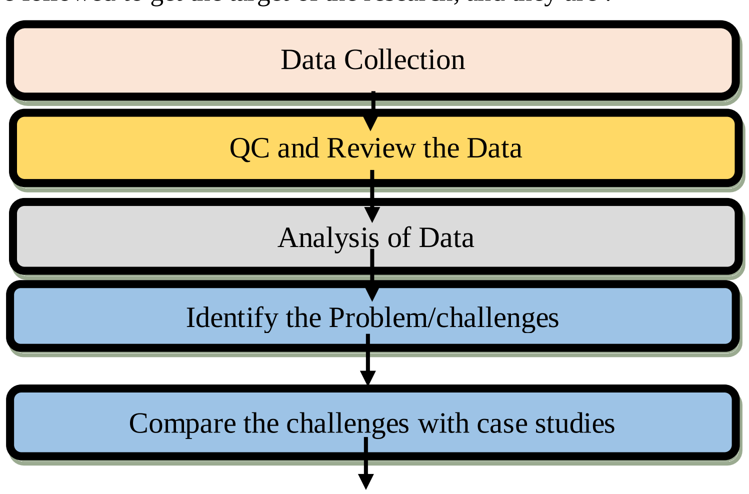
In heavy oil field of Sudan, this field contains heavy oil in multiple reservoir of bentiu formation. This primary recovery around 18-20%, plan is made for thermal enhanced oil recovery application early to maximize the recovery. (Tewari, et al, 2011).

Methodology

The Geological data, reservoir data and production data for Heavey Oil Sudanese field has been collected and used for analysis to investigate the main challenge of CSS and to design the optimum selection criteria that can maximize the recovery factor. The Reservoir Properties (i.e. porosity, permeability, depth, initial formation pressure etc …) has been analyzed.

All these analysis will be implemented and presented in flow chart through steps in order to find the optimum suggestion.

The steps below must be followed to get the target of the research, and they are :



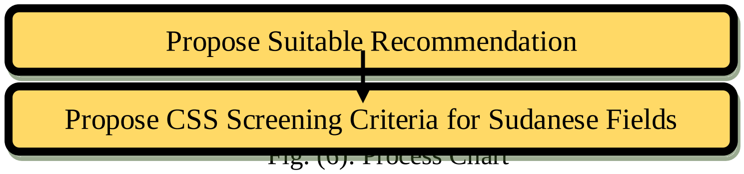


Fig. (6). Process Chart

Results and Discussion

Introduction

There are more than 10 heavy oil fields in Sudan which represent almost 60 % of Sudanese oil fields STOOIP in GNPOC (G. Bamboo (Bamboo Main & bamboo West, Lalouba, Eltayib, Hilba & Neem) in Petro-Energy (Block 6) Moga, FNE, FN and FC.

Implementation of EOR methods is a must for maximizing production and recovery from Sudan's oil fields. These methods must be studied carefully to assure proper selection and implementation.

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% OOIP). In a variation, CSS is applied under fracture pressure,

Overview of Thermal EOR Projects in Sudanese Oil Fields

There are Six EOR Projects in Sudanese Oil Fields Namely Three Thermal EOR (two CSS and one steam flooding) and two chemical EOR projects and one gas/N2 injection projects, the thermal projects are under implementation phase meanwhile the other Chemical /Gas projects are under Designing and Evaluation.

Also there are two EOR projects in Petro-Energy Company (CSS in FNE Oil Field and Steam Flooding (SF) in FNE Oil Field).

The thermal projects are under implementation phase meanwhile the other Chemical projects are under Designing and Evaluation

In this Paper there will be an overview of EOR Projects in Sudanese Oil Fields and the current status and way forward of this project as well as a comparison between different types of EOR in various phases.

- GNPOC
  - Bamboo Main
  - Bamboo West
  - Hilba
  - Tayib
- Petroenergy
  - FNE
  - FC

- Under Pilot Implementation
  - Bamboo Main
  - Bamboo West
  - FC
  - Hilba
- Full Field Implementation
  - FNE
- Under Pilot Design
  - Tayib.
  - Hilba.

The oilfield was put into development in June 2010. By May 2011 before the steam flooding study started, a total of 43 wells had been drilled, including one horizontal well; 36 wells have been put into operation, of which 23 wells are producing as cold, and 13 wells for steam stimulation; 33 wells were opened, with a daily oil production of 5722bbl, a daily fluid production of 6097bbl, a water cut of 6.1%, the total Original Oil In place (OOIP) is 298.7 MM STB, and the up to date recovery factor of reserves is 0.75%. The average daily production for steam stimulation is 2 to 3 times of the cold wells. see Table (1.4) and, Reserve and Cumulative Production. (Elbaloula, et al,2016).

Table (1.3): Reserve And Cumulative Production (Husham Elbaloula,2016)

Item	CHOPS	Thermal	Total
OOIP	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 recovery factor %	18.9	45.96	45.96
Up to date recovery factor %	1.07	2.52	3.60

CSS Performance Summary in FNE Field.

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 7&8).

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).

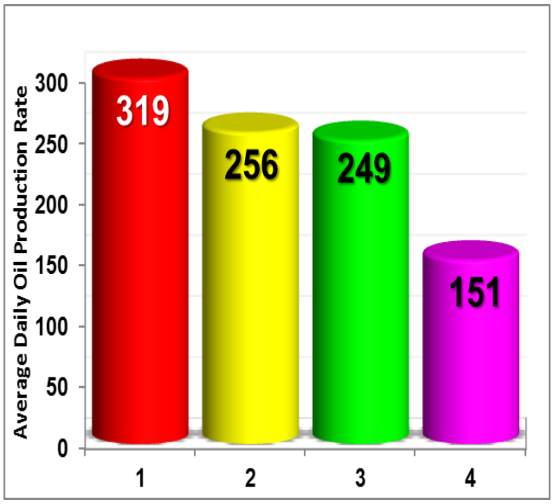


Figure (7):-The average oil daily production for each Cycle (Elbaloula, 2017)

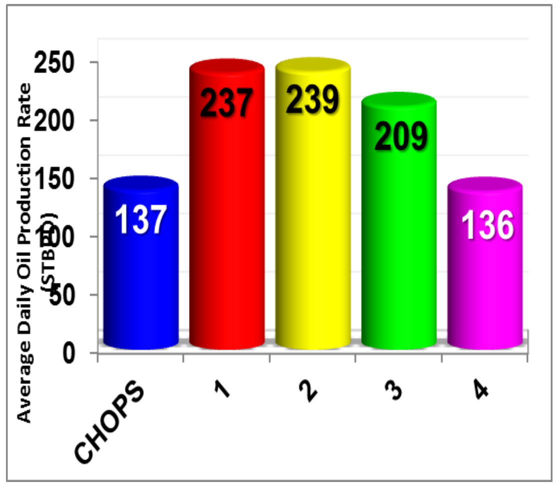


Figure (8):- Comparison between CHOPS and CSS Cycles for all wells (Elbaloula, 2017)

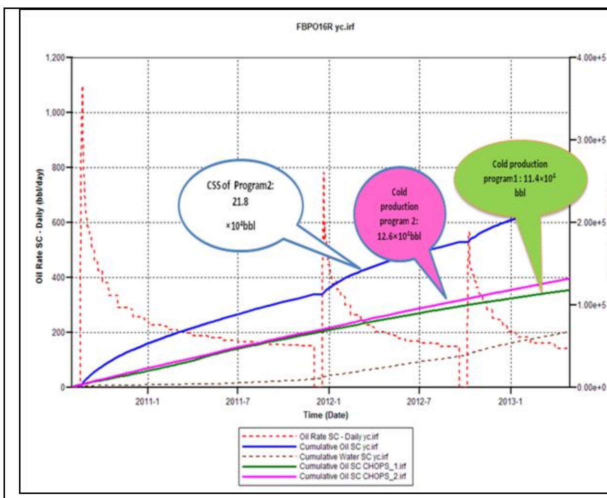


Fig. 9:- Illustrates The Comparison between the Cold And CSS Production from CMG Model.

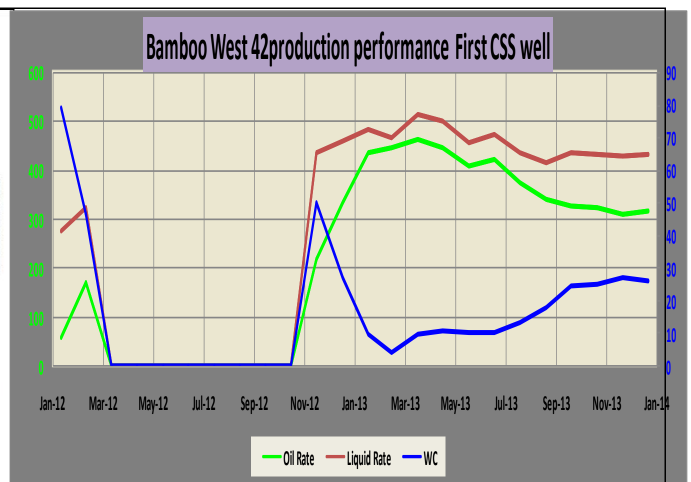


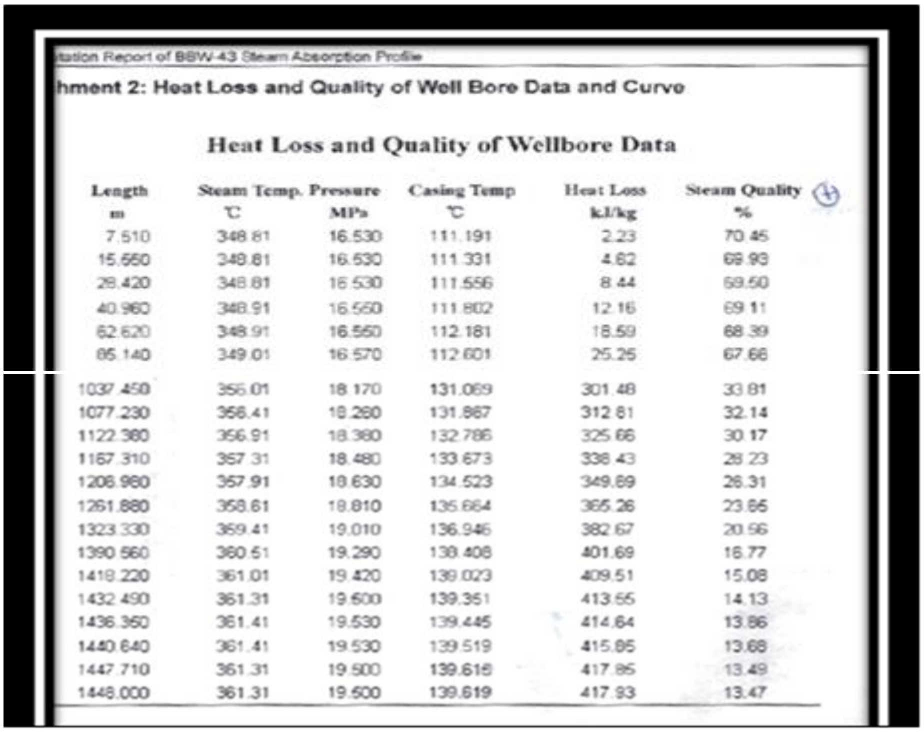
Fig. 10:- Bamboo West 42 Production Before And After CSS Implementation.

CSS Challenges in Heavy Oil Sudanese Fields.

After implementation of CSS in more four fields and review for almost 50 wells it has been found that many challenge faced the CSS implementation, during and after steam injection and some challenge for well selection before execution such as: -

1. Depth limitation (more than 1400m)

It has been found and confirmed that the steam quality will be very low less than 20% (see figure) by using the current available boiler in Sudanese oil filed which mean we inject water not steam and this can lead to produce high water cut so it's highly recommended to avoid wells with depth more than 13oo m



tation Report of BBW-43 Steam Absorption Profile

hment 2: Heat Loss and Quality of Well Bore Data and Curve

Heat Loss and Quality of Wellbore Data

Length m	Steam Temp. ℃	Pressure MPa	Casing Temp ℃	Heat Loss kJ/kg	Steam Quality %
7.510	348.81	16.530	111.191	2.23	70.45
15.660	348.81	16.530	111.331	4.62	69.93
28.420	348.81	16.530	111.556	8.44	69.50
40.960	348.91	16.550	111.802	12.16	69.11
62.620	348.91	16.560	112.181	18.59	68.39
85.140	349.01	16.570	112.601	25.25	67.66
1037.450	356.01	18.170	131.069	301.48	33.81
1077.230	356.41	18.260	131.867	312.81	32.14
1122.380	356.91	18.380	132.786	325.66	30.17
1167.310	357.31	18.480	133.673	338.43	28.23
1206.980	357.91	18.630	134.523	349.69	26.31
1261.880	358.61	18.810	135.664	365.26	23.65
1323.330	359.41	19.010	136.946	382.67	20.56
1390.560	360.51	19.290	138.408	401.69	16.77
1418.220	361.01	19.420	139.023	409.51	15.08
1432.490	361.31	19.600	139.351	413.55	14.13
1436.360	361.41	19.530	139.445	414.64	13.86
1440.640	361.41	19.530	139.519	415.85	13.68
1447.710	361.31	19.500	139.616	417.85	13.49
1448.000	361.31	19.500	139.619	417.93	13.47

Steam Injection Parameters (BBW-43)
1. Injection rate: 170t/d.
2. Injection Intensity: 160t/m.
3. Total amount: 800 tons.
4. Steam quality at wellhead: >70%.
5. Steam quality at well bottom : >50%.
8. Soaking Period 5-7 days.
6. Steam injection pressure at well head: ≤18~19MPa.
7. Steam Temperature at wellhead: > 270.

Fig (9). Steam Quality Result from CSS testing.

2. Horizontal wells
   There are many horizontal wells in Sudanese heavy oil fields and all of this well has been completed by normal casing and cementing and at the same time CSS in horizontal wells is new technology and it has been implemented in china only, so in this stage it will be very difficult to do CSS in horizontal wells.
3. High water cut.
   Normally the If the wells currently have high water cut it will not be easy to do CSS, because the high water can reduce the steam temperature and steam quality
4. High potential (good oil rate)
   Technically the high potential oil wells isn't challenge but it's very difficult for engineers to convince the top management to implement CSS in such wells.
5. Conventional completion wells.
   More than 40 wells has been drilled by normal casing and cementing and before CSS pilot implementation and when CSS successes it has been found that it's very difficult to do the CSS for this wells because the casing may be damage due to high temperature of injected steam
6. Production Csg.9 5/8

Some wells has been completed by production Csg.9 5/8 and currently only 7" casing packer is used, so it's very challenge to select wells with Production Csg.9 5/8 for CSS implantation unless special packer has been provided.

7. Commingle injection and production.
8. Long Soaking Period

Due to bad rig management and preparation many wells suffer from long soaking period and less lead to high water cut production.

CSS Screening Criteria for Sudanese Oil Field

After discussion and lesson learned from previous challenges and actual implementation the below table (2) has made as reference of CSS Screening Criteria for Sudanese Oil Field.

Table (2) CSS Screening Criteria for Sudanese Oil Field

API	Depth (m)	Visc.(CP)	Perm. (md)	Net pay (m)	WC (%)	Oil rate (bopd)	Well Completion	Sand quality	Completion Strategy	Well Type
8-25	< 1300	> 200	> 200	> 10	< 30	< 250	Thermal casing & cement	good	Single Zone	vertical

Lessons learn from BBW-43 & Ty-09
-The steam quality will reach downhole less than deigned

Lessons learn from BBW-39

Lessons learn from BB-22
-Most of The steam inj. Volume adsorbed by the bottom zone

Suggestion and Recommendation

After detail analysis and lesson learn from actual implementation the following suggestion has been summarize: -

- Conventional completion(37 wells)
  - To implement CSS in Conventional completion @ long CSS Cycle duration.
  - To inject N2 in the annuals with CSS
  - To use the Conventional completion wells as producer in Steam
- Conventional completion(37 wells)
  - To implement CSS in Conventional completion @ long CSS Cycle duration.
  - To use the Conventional completion wells as producer in Steam Flooding stage.
- Horizontal wells (15 wells)
  - SAGD
  - Replace by vertical well
  - To use it as producer in Steam Flooding stage.
- High Water cut (20 wells)
  - To use the high WC wells as Injector in Steam Flooding stage.
  - Minimize/optimize fluid rate
- Production Csg.9 5/8''
  - To use special packer for 9 5/8''(discuss with GWDC)
- High Potential (good oil rate)
  - Delay CSS implantation
- Comingle Zones
  - To inject by the same injection tubing
  - To use special injection tool
  - Squeeze and inject as single zone

Conclusion and Recommendations

- There are three thermal EOR Projects in Sudanese Oil Fields namely two EOR projects in Petro-Energy company (Cyclic Steam Stimulation (CSS) in FNE Oil Field and Steam Flooding (SF) project in FNE Oil Field), and one (CSS) EOR project-Bamboo ,Tayib& Hilba Oil Field thermal in Greater Nile Operating Company (GNPOC).
- The CSS projects are under implementation phase meanwhile the steam flooding project are under Evaluation.
- The CSS Screening Criteria for Sudanese Oil Field has been initiated and suggested.
- The Result show that the thermal EOR projects are very successful and almost gave double production from 130 bbl/day to 300 bbl/day in FNE Oil Field and from 280 bbl/day to 440 bbl/day in Bamboo Oil Field.

- It's highly recommended conduct the technology analysis for separate layer technology.
- It's highly recommended Conduct laboratory study to understand the effect of commingled well.
- The injection must be doing as a same of the modelling method to achieve the better production.
- It's highly recommended to optimize the CSS Operation and Injection Parameters in Sudanese Oil Field.
- In order to get maximum recovery from the wells it's highly recommended to select shallow depth, thermal completion and to avoid comingle layer injection or to use special technique for separate layer injection.

Nomenclature

API	American Petroleum Institute	MMSTB	Million Stock Tank Barrel
Bbl. /d	Barrel per Day	NP	Cumulative Production
BBW	Bamboo West	OEPA	Oil Exploration and Production Authority
BOBP	Barrel Oil per Day	OOIP	Original Oil in Place
CHOPS	Cold Heavy Oil Production with Sand		
CP	Centipoise		
CSS	Cyclic Steam Stimulation	RF	Recovery Factor
DTR	Development Technical Review	SF	Steam Flooding
EOR	Enhanced Oil Recovery	STB/D	Stock Tank barrel per day
EUR	Estimated Ultimate Recovery	STOIIP	Stock Tank Oil Initial In Place
FNE	Fula North East	%	Percent
IOR	Improved Oil Recovery	^{O}C	Degree Celsius
GNPOC	Greater Nile Petroleum Operating Company		
M	Meters		

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References

13th Development Technical Review (DTR), 2016 Petroenergy, Khartoum Sudan.

Alali, Y., Sanyal, T., Kyanpour, M., Bagheri, M., & Salter, T. (2016). A Comprehensive Study for Completion Plan for the Steam Flood Pilots. Society of Petroleum Engineers. doi:10.2118/179749-MS.

Ali, S. M. F., & Thomas, S. (1996, July 1). The Promise And Problems of Enhanced Oil Recovery Methods. Petroleum Society of Canada, Journal of Canadian Petroleum Technologydoi:10.2118/96-07-07, Alberta, Canada.

Alvarez, J. and Han, S.,(2013), "Current Overview of Cyclic Steam Injection Process", Journal of Petroleum Science Research, Volume 2,Texax,USA.

Butler, R.M (1991). Department of Chemical and Petroleum Engineering University of Calgary , Alberta, Canada ,Thermal Recovery of Oil AND Bitumen" by Prentice-Hall Inc. A Division of Simon & Schuster Englewood Cliffs, New Jersey, USA.

Boon, J. A. (1984, January 1). Chemistry In Enhanced Oil Recovery- An Overview. Petroleum Society of Canada, Journal of Canadian Petroleum Technology.doi:10.2118/84-01-08

Elbaloula, H., Pengxiang, H., Elammas, T., Alwad, F., Abdelsalam, M., Musa, T. (2016), Designing and Implementation of the First Steam Flooding Pilot Test in Sudanese Oil Field' and Africa',SPE-182790-MS , held at the SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition held in Dammam, Saudi Arabia.

GNPOC 32nd Development Technical Review (DTR), 2013, Khartoum, Sudan.

Gomez, J., Hughes, R., Hildalia, M.Toyo, Denssy., and Jose, B. , (2012) , ''Fracturing With Viscoelastic Surfactant Fluid in Cyclic Steam Injection Wells - A Synergy for Heavy Oil Recovery." SPE -153536-MS Conference paper

Green Don W., Willhite G. Paul, (1998),"Enhance Oil Recovery"Society of Petroleum Engineers, SPE text book series vol 6 , Richardson Texas .

Haytham A.Mustafa, Ali Faroug, Enas Mukhtar,SUDAPET; ;Husham Elblaoula, Badreldin A. Yassin SPC-OEPA; Tagwa Musa Sudan University of Science and Technology.Leksono Mucharam ITB Fadul Abdalla GNPOC.

Husham and ELamin (2016) Design and Implementation of Enhanced Oil Recovery Cyclic Steam Stimulation (CSS) Program in Bamboo West Field-Sudan, Case Study, SPE 184114 ,SPE International Heavy Oil Conference and Exhibition, 8-10 December, Mangaf, Kuwait.

Speight J. ,(2009), Enhanced Recovery Methods for Heavy Oil and Tar Sands, Gulf Professional Publishing, Huston, USA.

Tewari,R., Abdalla,F., Lutfi, H., Keqiang, Y., Faroug, A., Bakri, H., Guocheng,L., (2011) " Successful Cyclic Steam Simulation Pilot in Heavy Oilfield of Sudan" at SPE Enhanced Oil Recovery Conference, 19-21 July, Kula Lumpur, Malaysia.

Thomas S., (2008) "Enhanced Oil Recovery – An Overview" , Oil & Gas Science and Technology – Rev. IFP, Vol. No. 1.Alberta, Canada.

Wegis A. (2001). Multi-Zone Injection by Limited-Entry Through Tubing, SPE 66752, San Antonio, Texas, 26–28.

Yongbin W., Desheng M., Shangqi L., Hongzhuang W., and Xin Z.,(2010). 'EOR of Superheated Steam Injection in Shallow Heavy Oil Reservoir: A Case Study, Society of Petroleum Engineer, SPE-131224-MS, China.

Biography

Husham A. Elbaloula is a Simulation Engineer at Petro-Energy-E&P and PHD Candidate , Lecturer & Researcher in Sudan University of Science and Technology, He has Nine (9+) years of diverse experience in oil and gas field development planning, Performance review, Reservoir Simulation, Reservoir Management and IOR/EOR, He earned BSc and Msc. In Petroleum Engineering from Sudan University of Science and Technology College of Petroleum Engineering & Technology and currently he is Petroleum Engineering PHD candidate in the same College, He has participated in more than 15 local and international Technical workshops, Conferences and symposium in (Sudan, KSA, UAE, India, Bahrain, Morocco and Canada), He has published eight (8) journals and conference papers, Reviewer for SPE & IEOM and participated in five (5) Enhanced Oil Recovery projects in Sudanese Oil fields, and Conduct more than 15 training courses in the area of IOR/EOR for different training centers and companies.

He is working as Lecturer and Researcher Sudan University of Science and Technology College of Petroleum Engineering & Technology since 2013 up now.

Volunteering in SPE as Young Professional Chairperson – Sudan Section and SPE Ambassador Lecturer & President for IEOM SUST Student Chapter 2017

Dr. Tagwa A. Musa is an Associate Professor, and Dean of College of Petroleum Engineering & Technology-Sudan University of Science and Technology, she earned BSc in Petroleum Engineering from Sudan University of Science and Technology, Masters and PHD in Petroleum Engineering from China University of Geosciences, Wuhan, China, she has more than 10 published journal and conference papers. She supervised many Postgraduate Students (Bsc. 20 groups, Msc. 16 Students and 3 PHD Students). She is member of SPE, SAPEG, IEOM, SES, and SWPI, She Received IEOM Women in Academia and Industry Award, Morocco, 2017, Faculty Advisor for IEOM SUST Student Chapter 2017 and Membership Director for SPE Sudan Section since 2015 up to Now.

She is External Examiner for Department of Petroleum and Energy- college of Earth Science Dodoma university Tanzania since 2011 up to now.

Reviewer and Technical Committee for many journals and conference such as SPE, Elsevier… etc.

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