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Implementation of Chemical EOR as Huff and Puff to Improve Oil Recovery for Heavy Oil Field by Chemical Treatment SEMAR Cast Study Bamboo Oil Field

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Abstract

Bamboo field is located in block 2A Muglad Basin covers an area of 144 Square km. It consists of multi block, multi-layered under-saturated sandstone reservoir of late Cretaceous ages barried at depth ranging from 1000 m to 1700 m with crude oil viscosity ranges from 70 cp to 3000 cp. The total Field STOIIP and Recovery Factor (RF) are currently estimated at around 506MMSTB and 18% respectively through primary depletion. Up to date; the field had recovered more than 75% of the EUR.

The field initially produced around 20,000 STB/Day with early water breakthrough and very minimal gas production rate until today. However the production rate declined rapidly when the water production rate increased. Major factors that contributed to this problem are possibly due to the fingering and water conning. Currently the field is producing around 8000 STB/Day with water cut around 80% and keeps increasing.

Schemes in enhancing and prolonging the already decline production and diminishing reserves strategically call for timely implementation of Enhanced Oil Recovery (EOR) process. Among various Enhanced Oil Recovery (EOR) process and techniques, Bamboo reservoirs appear especially amenable to thermal injection process. But Sudapet, ITB and PERTAMINA (an especial study) came up with different solution which is Huff and Buff of Chemical EOR, This proved to be one of the practical, promising and potential options in enhancing the recovery factor in Bamboo Field.

This paper will discuss the lab study scope, includes the core sample, fluid sample, phase behaviour test, spontaneous Imbibition Test, Compatibility test, Viscosity Mixture and core flood, well selection analysis as well as the implementation of SEMAR as pilot project in Bamboo Oil Field.

After implementation of the pilot as Huff and Puff in three wells the results show that about 18,000 STB of oil gained from adjacent wells, which indicate that SEMAR is very interesting to be evaluated for further steps in chemical EOR implementation for continuous Injection.

Introduction and Literature Review

Greater Bamboo fields are located in Block 2A area of Muglad Basin which consist of four (4) oil producing structures; namely Bamboo Main, Bamboo West (+Bamboo AG), Bamboo East and Bamboo South. The main producing sands are Bentiu-1, Bentiu-2 & 3. Bamboo Main field was discovered by Chevron in 1982, Bamboo West field was discovered in December 1997 followed by Bamboo South in February 2000 and Bamboo East in September 2000.

Greater Bamboo is one of biggest field of GNPOC consisting of 25% of total GNPOC STOOIP and also contained 85% of the Heavy Oil Resources in GNPOC. The 1st oil production was commenced in July 2001 and a peak production of ~20Kpopd was achieved in July 2002. As in Jan 2016, the total cumulative oil production of Bamboo fields is 64MMSTB, recovery of 12.6% of the total STOIIP of 506.4MMSTB (GNPOC, 2015).

The current performance ahows that; the fields producing around 8 Kbod with average water cut around 80%. All producers are producing with PCP, ESP or Beam Pump Unit (BPU). The fields contain heavy crude oils with more than 3000 cp that poses great challenges to iil production with conventional completion and production motheds which most likely the major concern for very low oil recovery. The reservoir rock and crude oil properties for Greater Bamboo fields summarize as per table 1.

Table 1—The reservoir rock and crude oil properties for Greater Bamboo fields (GNPOC, 2015)

Parameters	Greater Bamboo
Reservoir Formation	Bentiu & Aradeiba
Top Depth, mKB	1300
Initial Res, Pressure, psia	2300
Current Res, Pressure, psia	1600
Temperature, C	60-70
Porosity, Fraction	0.23
Permeability, mD	300-10000
Oil Gravity, API deg	15-25
Viscosity, cp	70-3000

Table 2—Screening Criteria for Surfactant Application in EOR

Property	SPE Text Book	SurPlus ITB
API Gravity	> 20	≥ 10
Viscosity	< 35 13	< 100
Rock Type	Sand	Sand , Carbonate
Thickness	NC	NC
Depth, ft	<9000	<12,000
Temp, F	< 200	300
Perm, md	>10	> 10

Since the declining production take place for that our strategy to go for implementation of Enhance Oil Recovery (EOR) process. After detail screening study it has been conclude to use chemical EOR in Bamboo field reservoirs (Table 2), Feasibility studies shows that surfactant injection is potentially the most practical and viable option.(J.J Taber, 1997).

SEMAR: Smart ChEmical Modifier for Accelerated Recovery

The new chemical (SEMAR) when mix with heavy oil phase can generates an oil-rich colloidal dispersion which has low viscosity value. This type of chemical is also able to alter oil wetting to water wetting which can make oil mixture easy to flow in porous media.

Wetting means that portion of the process in which a liquid spreads over the surface of a solid particle or the penetration of agglomerates through a liquid. The process of absorbing a wetting phase into a porous rock. Imbibition is important in a water drive reservoir affecting areal sweep. Spontaneous imbibition refers to the process of absorption with no pressure driving the phase into the rock (Nugroho, 2012).

Imbibition Process: It is possible for the same rock to imbibe both water and oil, with water imbibing at low in situ water saturation, displacing excess oil from the surface of the rock grains, and oil imbibing at low in-situ oil saturation, displacing excess water. An imbibition test is a comparison of the imbibitions potential of water and oil into a rock. The wettability of the rock is determined by which phase imbibes more.

Wetting Phase: Stronger Wetting phase is related to lower contact angle between liquid phase and the solid. Also, the lower contact angle is related to stronger ability to imbibe non-wetting fluid. These phenomena can be obtained by Spontaneous Imbibition Test using Amott Imbibition Cell.

Non Wetting Fluid is displaced by Wetting Fluid, or in this case SEMAR with strong wetting property can displace oil phase from the solid surface.

Nugroho (2012) discussed a case study in Sugai Lilin oil field and found that from recent laboratorium EOR study, it showed that oil reservoir system in Baturaja limestone reservoir is considered as a strong oil wetting, especially in low permeability layer. This penomenon was also shown by value of the SOR which is greater than 35 %.

Al-Sinani (2016) illustrate the implementation of chemical EOR in Oman oil field and conclude that comparing to water flood, initial recovery factor evaluation indicate possible improvement of up to 18% (per pore volume injected) in unit A which has more mature water flood where water cut exceeding 80% but less oil volume. Recovery improvement in unit B, a less mature water flood reservoir unit, was not remarkable. Post job analysis and review claims this due to the relatively immature water injection and thus lower water cut in this reservoir unit. Unit B is also three times thicker than unit A, which meant it received a lower chemical volume, which might have resulted in a lower recovery performance.

In Sudanese oil fields this pilot consider as first chemaical EOR pilot laboratory study and implementation as well.

Chemical EOR (SEMAR) for Heavy Oil

Combinations of micro emulsion effect, imbibitions effect and viscosity reduction caused by implementing SEMAR will improve PI significantly and increase oil production as shown in Fig (1).

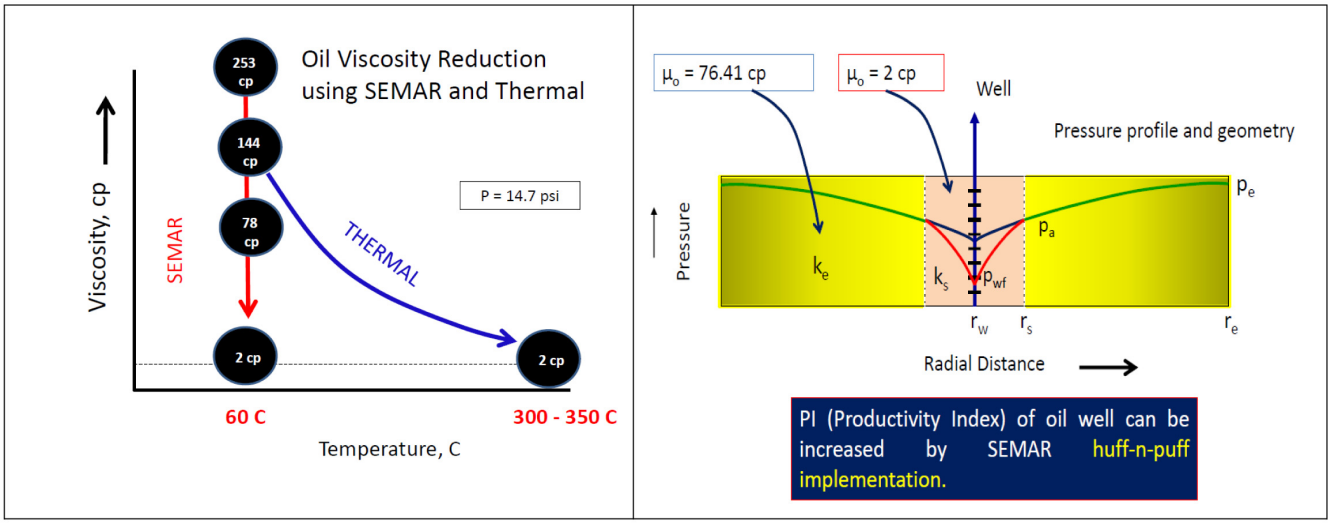

Figure 1—Oil Viscosity Reduction using SEMAR

SEMAR previous application

SEMAR has proven successful at many fields in Indonesia and succeeded at Daleel petroleum of Oman. From all field projects, some of them show an excellent performance over the expectation.

1. Arahan-Banjarsari field, the oil gain is doubled more than a year after chemical injection.
2. Sungai Lilin field is located in Sumatra, Indonesia .the oil is producing from carbonate reservoir. Oil type is resinic and semi–asphaltic with API 34, very sticky to reservoir rock .the huff and puff program with SEMAR has proven to increase oil production significantly.
3. Bentayan field has gained more than 10,000 barrel of oil per month after injecting SEMAR by using huff and puff method, the oil in the formation is heavy with API less than 20 with sandstone formation.
4. Zamrud field is located in Sumatra; it has a sandstone formation with resinic oil, the production increased significantly at the injection wells and the neighboring/monitoring wells using the huff and puff method.
5. Daleel field is located in Oman, Middle East .the oil is produced from carbonate reservoir, the incremental oil gain is more than twice from the forecast baseline after SEMAR injection using huff and puff method.

SEMAR Laboratory Tests Analysis and Results

The Objectives of the entire tests done using SEMAR are as follows:

- ✓ Find the most compatible chemical for EOR through phase behavior, compatibility test, and spontaneous imbibition test, emulsion viscosity measurement and core flood test.
- ✓ Provide information about the effect of the chemical type and concentration on its capability in recovering oil from the core.
- ✓ Investigate the effect of temperature on chemical effectiveness and the compatibility of chemical with the rock.
- ✓ Determine the cumulative of oil recovery after performing spontaneous imbibition test using Semar Chemical.
- ✓ Measure and analyze viscosity of oil mix with Semar Chemical for various volume compositions.

Table 3 show the density and viscosity of the samples from Bamboo field. (GNPOC-2012)

Table 3—Density and Viscosity Data

No	Sample	ρ(gr/cc) T= 26oC	ρ(gr/cc) T= 70oC	μfluid(cp) T= 70oC
1	Bamboo#20Brine	0.9883	0.9776	0.6674
2	Bamboo#20Oil	0.9081	0.9004	76.411

Phase Behavior Test Result

From phase behavior tests on BBW#20 field, with various SEMAR, show that 13 out of 15 formulas were able to form middle phase micro emulsion between oil phase and water phase. Then, by considering efficiency of the results, the best 9 of13 formulas were selected for further selection using the spontaneous imbibitions tests (Table 4).

Table 4—Chemical Used in the Study

No	Chemical	No	Chemical
1	Formation Water (BB-2)	6	S13B0.5%(BB-6)
2	S7A0.3 % (BB-10)	7	S13C 0.5%(BB-9)
3	S100.5%(BB-11)	8	S16A0.6% (BB-1)
4	S12A1%(BB-3)	9	S16A0.5% +STA-30.2% (BB-5)
5	S13A* 1% (BB-4)	10	S18A0.5% (BB-7)

Spontaneous Imbibition Test

Submerge oil saturated-core into a liquid solution at reservoir temperature, with no pressure asserted. Spontaneous imbibition refers to the process of adsorption with no pressure driving the phase into the rock. Result shown in Fig (2) and Table (5)

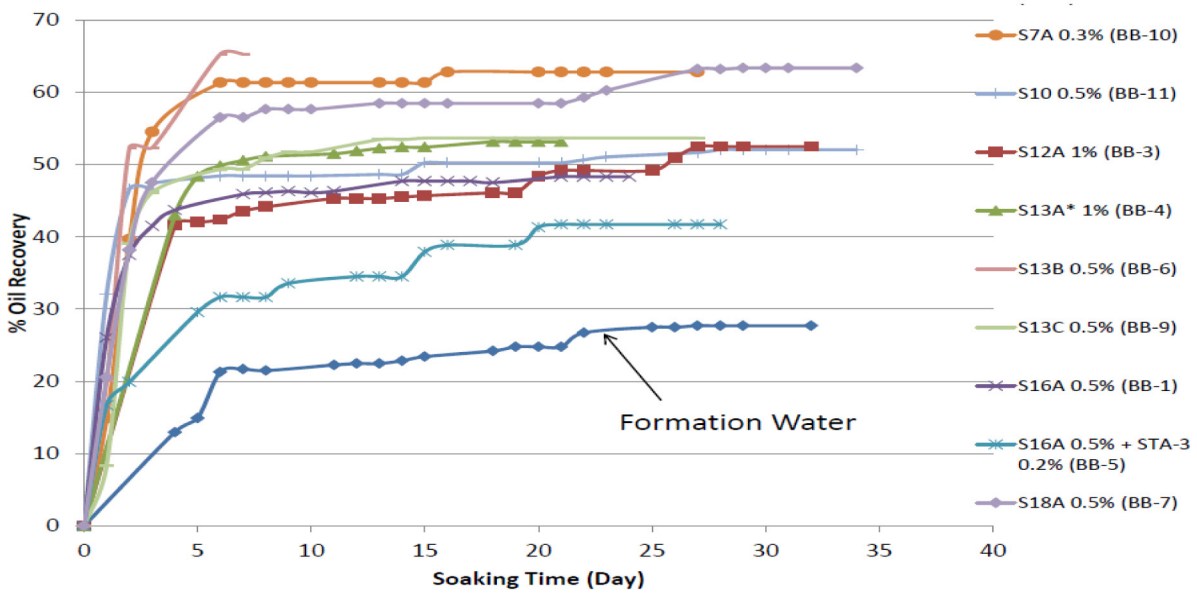

Figure 2—Spontaneous Imbibition for Bamboo #20

Table 5—Summary Spontaneous Imbibition Results

No	SEMAR Formulation	Sample Code	Volumeoil (cc)	ø(%)	Soaking Tim(Day)	%Oil Recovery	Imbibition Status
1	Brine	BB-2	5.16	26.07	32	27.69	Completed
2	S7A0.3%	BB-10	4.11	26.14	9	61.35	Completed
3	S100.5%	BB-11	4.96	21.97	9	49.84	Completed
4	S12A1%	BB-3	5.14	26.98	32	52.50	Completed
5	S13A*1%	BB-4	5.42	27.54	21	53.16	Completed
6	S13B0.5%	BB-6	4.78	24.84	7	62.28	Completed
7	S13C0.5%	BB-9	4.66	25.35	9	50.88	Completed
8	S16A0.5%	BB-1	4.99	23.68	24	48.31	Completed
9	S16A0.5%+ STA-30.2%	BB-5	5.27	26.38	22	41.71	Completed
10	S18A0.5%	BB-7	6.12	25.82	8	57.65	Completed

$$q = \frac{7.08\,K\,K_{ro}\,h}{\mu_o}\,\frac{(P_e - P_w)}{\ln(r_e/r_w)}$$

From Darcy equation and Fig (3) it's clear that when Viscosity of oil is reduced to 38 times oil productivity of the will increase 38 times

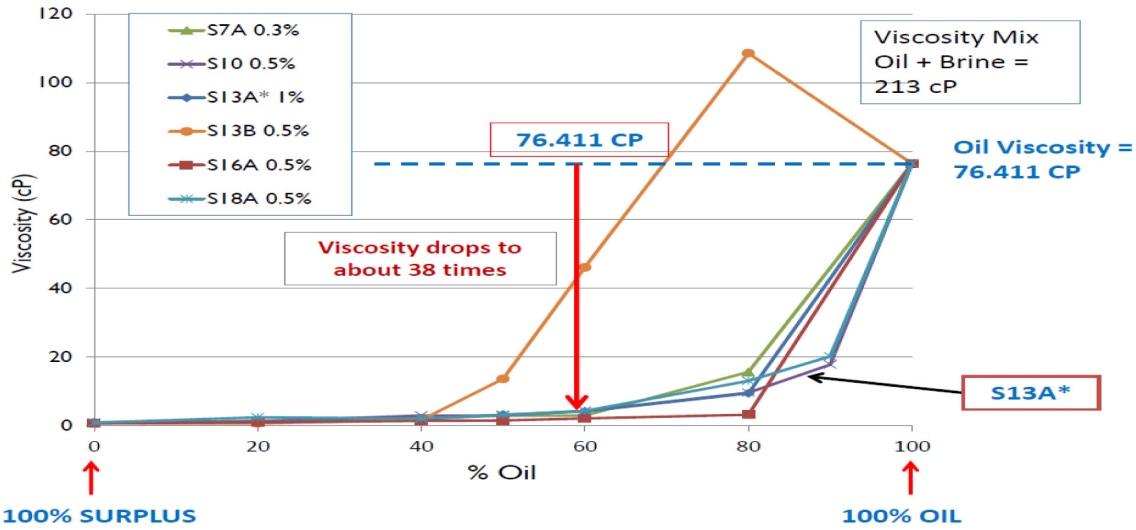

Figure 3—Emulsion viscosity of Oil and SEMAR

From Fig (3), two types of SEMAR has been selected to be use in the core flood tests.

These types are 1\ S18A 0.5% and 2\S13A* 1%. Fig 4 and 5 show the Recovery Factor & Water Cut versus Pore Volume from S18A 0.5% and S13A 1% respectively. Compirson between the recovery factor and water cut for mentioned types of SEMAR are clear in fig 6. The core flood tests show an increment in the recovery by using these types of SEMAR (Table 6). Table 7 show a summary of oil recovery from laboratory results.

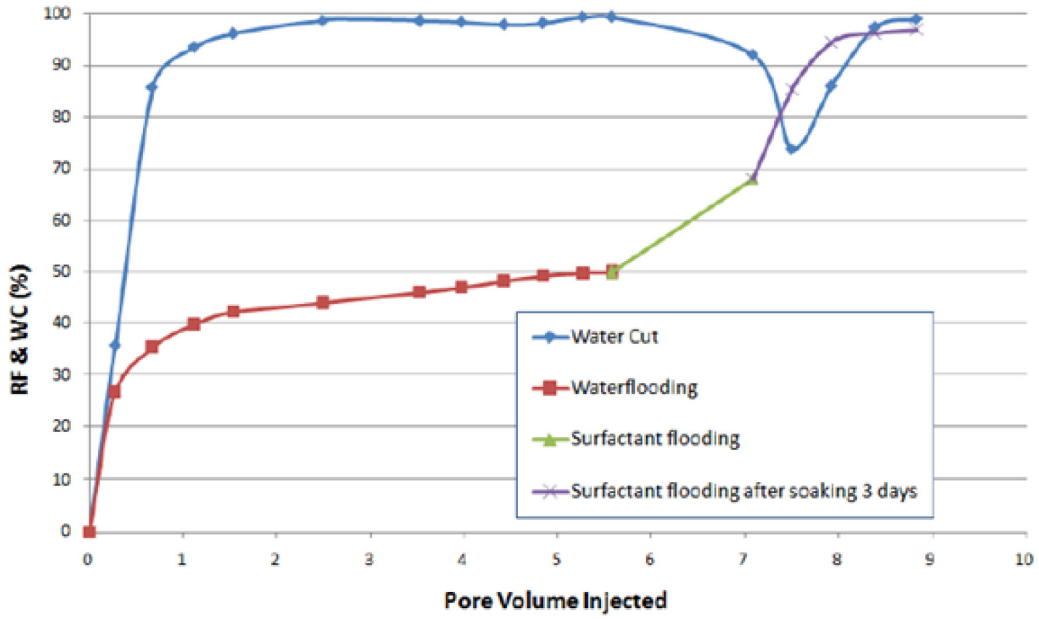

Figure 4—Recovery Factor & Water Cut Vs. Pore Volume Injected By SEMAR (S13A*)

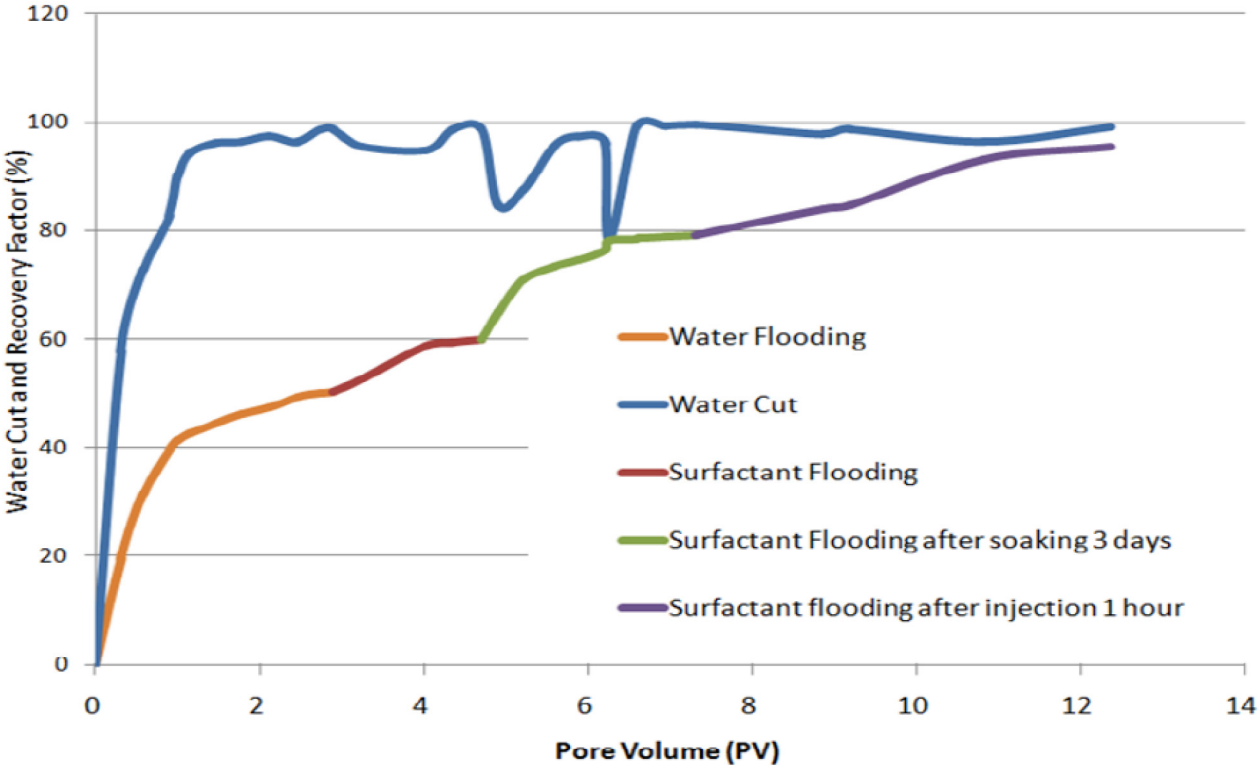

Figure 5—Recovery Factor & Water Cut Vs. Pore Volume Injected By SEMAR (S18A)

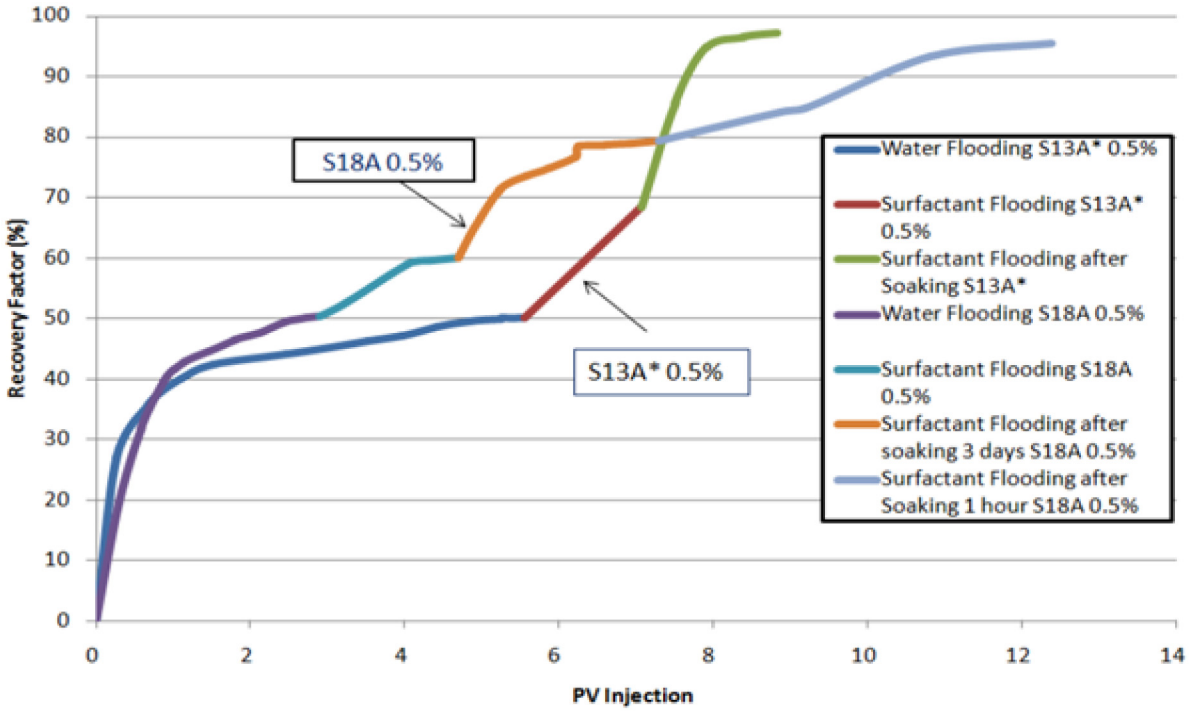

Figure 6—Recovery Factor & Water Cut Vs. Pore Volume Injected By SEMAR (S13A* & S18A)

Table 6—Core Flood Test Results Using Semar S13a* 0.5% and S18a 0.5%, Respectivel

Method	CoreFlood#1(CoreBB-15) UsingS13A*0.5%; Ø= 23.92%		CoreFlood#2(CoreBB-19) UsingS18A0.5%; Ø= 26.48%	
	Incremental Oil (%)	Total Recovery Factor (%)	Incremental Oil (%)	Total Recovery Factor (%)
Water Injection	50	50	50.3	50.3
Chemical Injection (1)	18.31	68.31	9.64	60.06
Soaking Time(1)	3Days		3Days	
Chemical Injection (2)	28.81	97.12	19.15	79.21
Soaking Time(2)	Non		1hour	
Chemical Injection (3)	Non		16.27	95.48

Table 7—Oil Recovery Summary from lab.

Core Flood	Total Incremental Oil Recovered (%)	Total RF (%), Including Water Flood / Drive
Core Flood# 1 (CoreBB-15) S13A*0.5 %	47.12	97.12
Core Flood# 2 (CoreBB-19) S18A0.5 %	45.06	95.48

SEMAR huff and Puff Application in Bamboo oil field

For heavy oil reservoir SEMAR Huff and Puff Technique need to be implemented in an oil production welll to improve the oil production before implementing a continuios flooding.

Three wells has been selected for SEMAR huff and puff (Fig 7) which are BBW-21, BBW-27 and BBW-23 as shown in the structure map Fig (9).

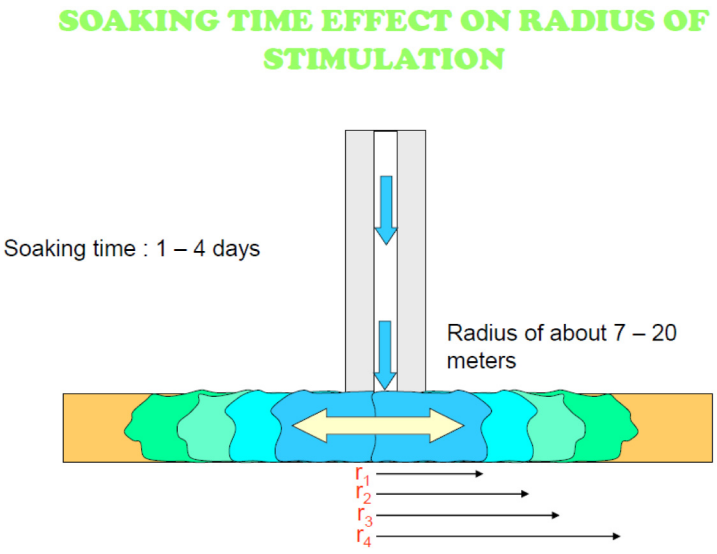

Figure 7—Huff and Puff mechanism for Bamboo West Oil Field

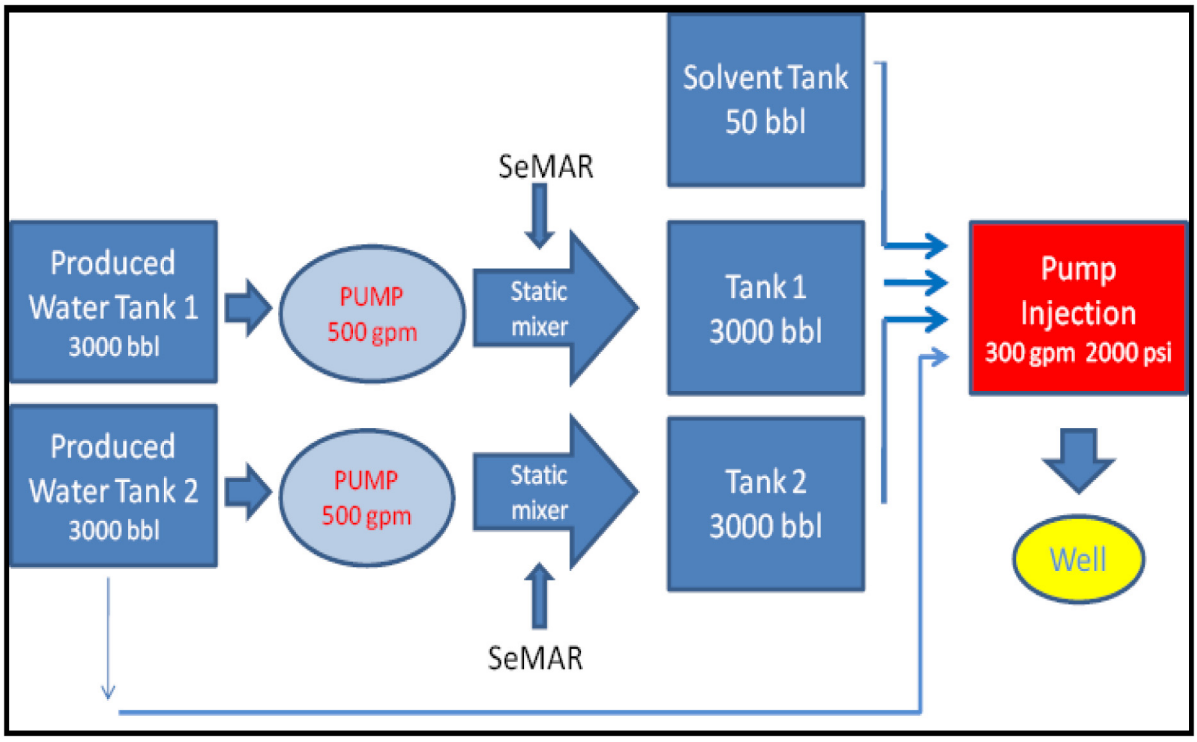

Figure 8—Modified Process Schematic Layout

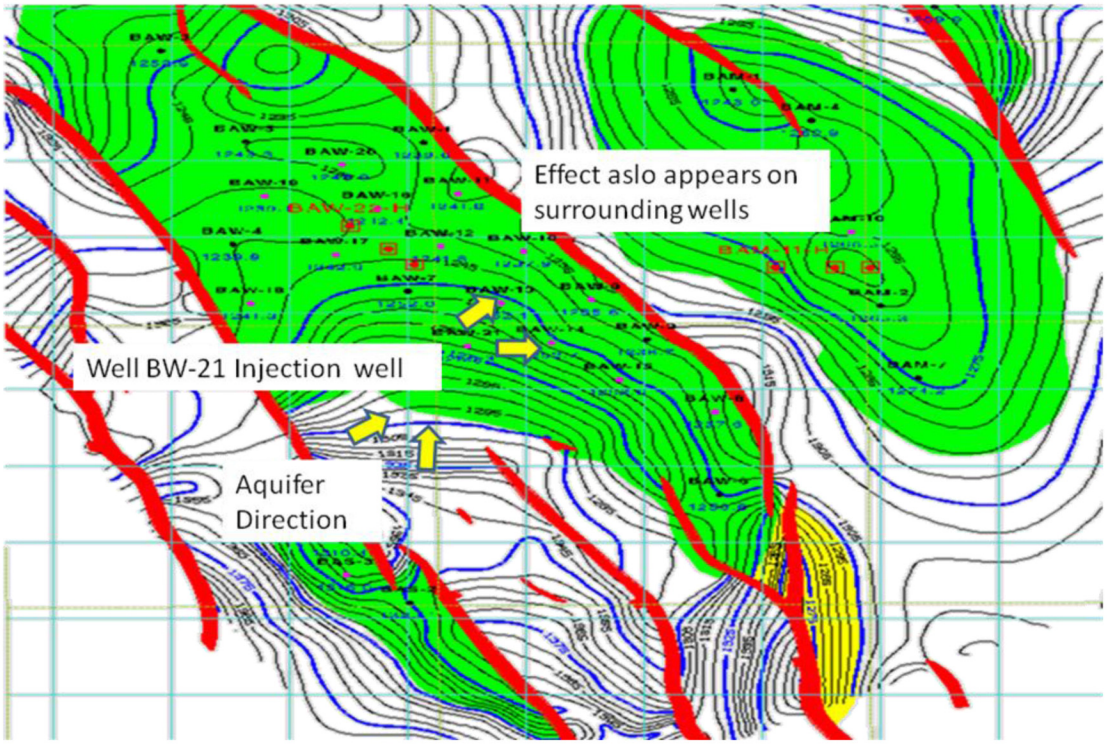

Figure 9—Structure map for BBW SEMAR wells (OEPA, 2012)

Operational Steps: BBW-21 as an Example

- BBW-21 was stopped, isolated towards OGM/FPF, and Casing Annular pressure was closed.
- The tubing Master Valve and flow line Ball Valve were closed.

- ➢ All surface piping was checked, injection connection from High pressure pump to annulus was pressure tested at 1000 psi. Held for 10 minutes.
- ➢ 50 bbl pre-flush liquid (diesel) was pumped against perforation.
- ➢ During this operation injectivity was tested. Pressure checked for desired injectivity rate of 2-5 bbls/min.
- ➢ Fracture pressure is 2500 psi and Tubing column head is 1500 psi. Limit the injection pressure less than fracture pressure.
- ➢ Surface pressure measured to be less than 1000 psi.
- ➢ **Max pressure reached was 270 psi**
- ❖ Followed with SEMAR solution Injection @ as mentioned below:
- ➢ SEMAR Sol. 1500 bbls, 3.0 % concentration.
- ➢ SEMAR Sol. 1500 bbls, 1.5 % concentrations.
- ➢ SEMAR Sol. 1800 bbls, 0.6 % concentration.
- ➢ SEMAR Sol. 200 bbls, 1.8% concentrations.
- ➢ Start 05:06 pm July 27th
- ➢ Finish 02.30 am July 29th
- ➢ Total Time 33,5 hours
- ➢ Average pumping rate 2 bpm
- ➢ Annulus Pressure 0 psi
- ➢ Total injected Volume 5250 bbls (Fig 8 show the process schematic layout for injection)
- ➢ The above operation was followed by pumping 200 bbls of water as over flush.
- ➢ Soak the well for 7 days
- ➢ Open well BBW-21 at 60% - 80% of the previous liquid rate and monitor the production performance for one month, if no improvement in the oil production then gradually increase the liquid rate to its initial ESP pump parameters and monitor its production performance for a period of 3 – 6 month (SEMAR Team to advice timing for changing the ESP pump setting).
- ➢ Monitor the adjacent wells performance (BBW-13, BBW-14,BBW-7 AND BBW-15) to observe effect of chemical injection to surrounding wells for 3 - 6 months (subject to advice from SEMAR Team).
- ➢ Monitor produce fluid at production facilities to observe by-product flow back from chemical injection and report any traces of SEMAR component in the produce fluid for further analysis.

Post Surveillance of Production Performance at Huff & Puff Well and Surrounding Adjacent Wells

- ➢ Well Production Test

a. Well Production Test (Liquid, Oil, Water) with existing facilities (Micro Motion & Test Separator)
b. Measure Water Cut at Laboratory by taking sample fluid from Well

- ➢ Monitoring Wellhead Pressure at least once a day
- ➢ Monitoring Pump Parameters
- ➢ Setting Rate Of Production 60-80% from initial rate
- ➢ Monitor Dynamic Fluid Level

Operational Challenges

- Logistical problems before and during the injection operation post Heglig Invasion
- Lack of accurate metering during the implementation of the project
- Problems in cars availability to collect water samples from well heads and transfer them to the lab
- Frequency of fluid rate measurements is too long

SEMAR Performance BBW 21

BBW 21 Injection started on 27 July 2012, production resumed on 5 August 2012. The gain is not significant, it is related to SEMAR chemical spreading in the reservoir and captured in the adjacent wells following the water flow in reservoir as shown in Fig (10).

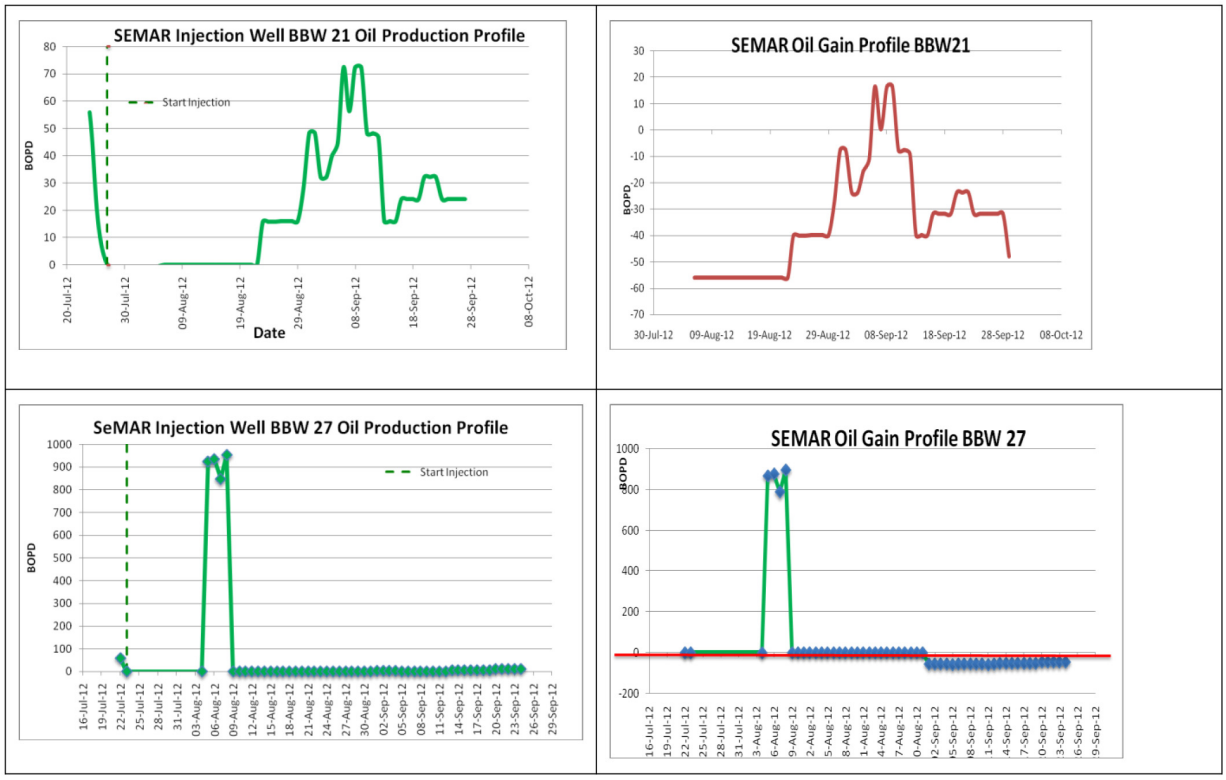

Figure 10—Performance of BBW 21 & 27

BBW27 started injection on 23 July 2012, starting production on 2 August 2012.

The gain shown very significant 895 bopd (Fig 10), as result from the drop of mixture viscosity oil & water SEMAR can make continous oil dominating phase in reservoir (from continous water phase). Viscoemulsion can bring maximum oil to the production well BBW27 (see illustration picture below Fig 11).

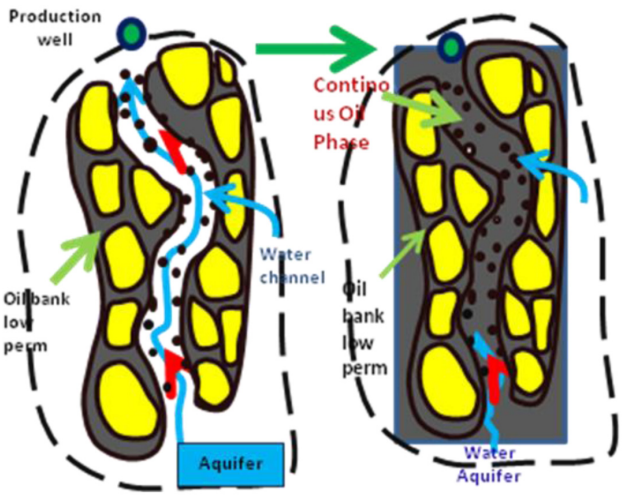

Figure 11—Finguring due to chemical injection

Eventhough viscosity of mixture water & oil is drop significantly compare oil viscosity, but mixture viscosity is 5 times than water viscosity then this situation make pump impeler work very hard and after surpass the ultimate condition the ESP pump become shut down

Performance of nearby wells

Well monitoring started on 5 August 2012 and response started on 16 August 2012.

BBW23 started injection on 19 July and BBW 27 on 23 July 2012 as the nearest Huff & Puff injection well from Monitoring well BBW 17.

Response from injection in BBW 27 to BBW 17 happen before 16 August 2012 (21 days) and from BBW 23 on 29 August 2012 (41 days).

The gain in BBW 17 is significant, as result from SEMAR injection in BBW 23 and BBW 27 spreading following the water flow in and captured by oil bank surround BBW 17 (Fig 12).

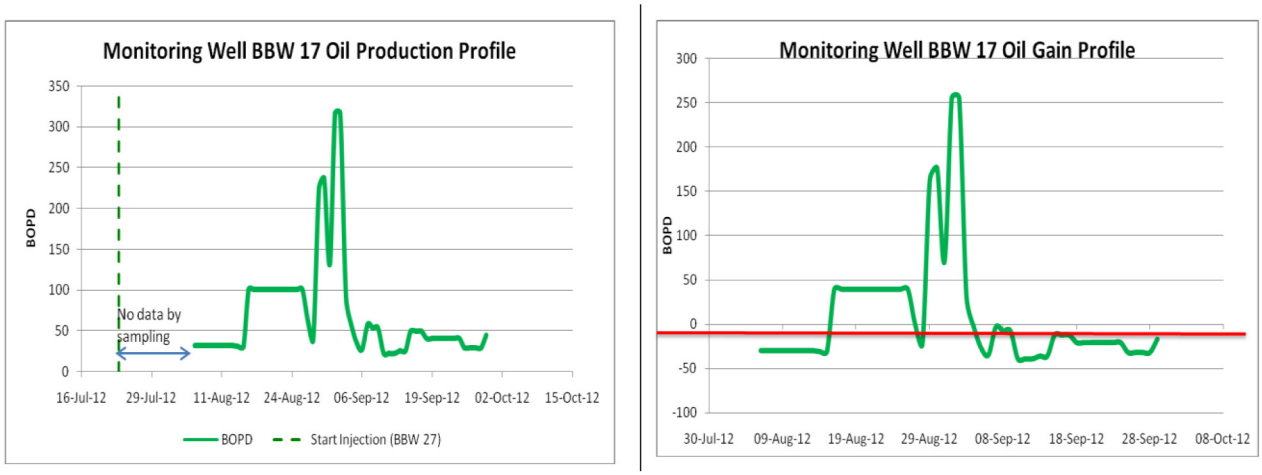

Figure 12—Performance of BBW 17

The maximum gain is 256 bopd, with cummulative gain (until the oil production drop back to previous value before the gain) is 1074 barrel oil.

Results Summery

- Incremental from BBW 27 max 895 bopd, cummulative 3427bbl oil, average 857 bopd for 4 days.
- Incremental from BBW 13 max 263 bopd, cummulative 975bbl oil, average 45 bopd for 22 days.
- Incremental from BBW 14 max 108 bopd, cummulative 2268bbl oil, average 87 bopd for 26 days.
- Incremental from BBW 17 max 256 bopd, cummulative 1074bbl oil, average 37 bopd for 29 days.
- Incremental from BBW 22 max 551 bopd, cummulative 6183bbl oil, average 177 bopd for 35 days.
- Incremental from BBW 25 max 165 bopd, cummulative 3265bbl oil, average 63 bopd for 52 days.

Conclusion and Recommendations

- ➢ With Brine, no emulsion is formed with the oil,
- ➢ In glass tube (without Chemical EOR), the oil phase will stick on the wall glass.
- ➢ From Imbibition test, oil recovery obtained using SEMAR is twice higher than that obtained using Brine.
- ➢ Mix between SEMAR and Oil could reduce Oil viscosity from 76 cp to about 2 cp. This is a new finding.

- ➢ Combinations of micro emulsion effect, imbibition effect and viscosity reduction will improve PI significantly and increase oil production with implementing huff & puff SEMAR.
- ➢ RF of Laboratory SEMAR (97%) correlates to 36-50% in Field Performance.
- ➢ For improving oil production in Bamboo reservoirs Huff and Puff techniques with SEMAR S-13A* (0.5%) is recommended.
- ➢ Total Cummulative Oil Incremental (gain) : 17192 bbl oil
- ➢ Total Maximum Oil Incremental (gain) : 2238 bopd
- ➢ Total Average Oil Incremental (gain) : 1266 bopd
- ➢ Since there is response in nearby wells it's highly recommened to implement the SEMAR as Continuous injection after huff and puff.

Acknowledgements

The authors would like to thank Ministry of Petroleum, ITB and SUDAPET Co. Ltd. for the permission to publish this paper.

Nomenclature

API	American Petroelum Institue
BBL	Barrel
BBW	Bamboo West
BOPD	Barrel Oil per Day
Cp	Centi poise (viscosity)
EOR	Enhanced Oil Recovery
FPF	Field Processing Facilcity
Ft	Feet
OEPA	Oil Exploration & Production Authorty
GPM	Galon per Minutes
IOR	Improved Oil Recovery
OGM	Oil Gathering Manifolt
PI	Production Index
Psi	Pound sequar Inch
STB	Stock Tank Barrel
STOIIP	Stock Tank Oil Initial In Place
GNPOC	Greater Nile Petroleum Operating Company

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