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Review

An investigation of the efficacy of enhanced oil recovery by means of micro-organisms in Niger Delta Reservoir

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Abstract

Microbial Enhanced oil recovery (MEOR) is the improvement of oil recovery by the injection of micro-organisms or their products into depleted oil reservoirs to increase recovery and extend oil production. This study aims to know the efficiency of the method in the Niger Delta region, hence Treated sandstone cores were obtained from some fields in the Niger Delta, re-saturated with brine and dead crude of specific gravity 35.7 ^{0} and viscosity 0.41cp and treated with Bacillus and Pseudomonas species of micro-organisms, oil displacement experiments were performed at simulated reservoir conditions. The results obtained show an average reduction in residual oil saturations in the core samples of 23% due to microbial flooding against a 35% residual saturation at the end of conventional water flooding. The recovery efficiency also improved by an average of 21.63%, however, in the microbial runs of the first two samples the results showed that the incremental oil recovered disappeared gradually, indicating that these species of microbes are crude oil degrading, therefore it is recommended that a very rich and adequate source of nutrient be employed when using these organisms.

Keywords; Enhanced Oil Recovery, Pseudomonas and Bacillus Micro-organisms, Core plugs, Core flooding experiment.

INTRODUCTION

The quantities of reservoir fluids estimated to be commercially recoverable can only be exploited by drilling boreholes (production wells) into the hydrocarbon bearing zones, and allowing pressure gradient to force up fluids into these wells first by naturally available pressure then followed by artificial means or methods. The techniques or methods available to the petroleum engineer in achieving this goal of bringing or recovering these reservoir fluids to the surface are classified as Primary recovery method, Secondary recovery method and Tertiary recovery method.

In primary recovery, reservoir fluids are recovered at the surface by the initial and natural sources of energy available in the reservoir, then, if and when the naturally available pressure gradients or energies becomes clearly insufficient to produce the fluids at the desired rate or percentage, there is need to maintain the reservoir pressure/energies by supplementary means, to continue with fluid production as desired. The first supplementary pressure maintenance scheme is termed secondary, which is basically water flooding and gas flooding, that involves injection of pressurized water or gas into the oil bearing formation to displace oil thereby producing additional flow from the wells (Dake, 2001).

Unfortunately, even after both primary and secondary methods have been employed, only about twenty to thirty percent (20-30%) of the fluid estimated to be originally in place is recoverable, leaving over two-thirds of the original oil in place beneath the earth(Venable, 2009). Then tertiary recovery processes becomes the focus of the petroleum industry. Tertiary recovery methods generally fall into three categories; Miscible flooding, Chemical flooding, and Thermal flooding (Craft et al. 1991). But the additional oil produced by these

conventional tertiary methods is so unsatisfactory and economically unattractive that the oil industry is in dire and continuous search of enhanced oil recovery methods (EOR).

Microbial enhance oil recovery (MEOR) technique enables the improvement of oil recovery by injection of micro-organisms and/or their products into depleted oil reservoir (Behluigil et al. 2002). MEOR is used in the third phase of oil recovery from a well, which is the tertiary oil recovery stage (Fratesi et al. 2002). MEOR is one technique for recovering residual oil that offers the most timely and cost effective solution to reverse the decline in domestic oil production and increase reserve. It has unique advantages that make it an economically attractive alternative to other EOR processes (knappet al.1992).

In North West Alabama, Prof. Lewis Brown was able to extend the life of a field by seventeen years through the injection of special nutrients to feed indigenous micro-organisms and the field produced additional 400,000 barrels of oil at the cost of 11.3 per barrel of new oil. Also the Titan process injects a non-glucose nutrient formula into the reservoir and this non-glucose nutrient source induces the micro-organisms to become “active” in the reservoirs by changing the characteristics of their skin. The microbes then seek and surround oil droplets in the sand stones and Carbon strata. This activity dislodges and breaks up oil droplets, which significantly increases oil recovery. Udegbunam et al, 1991, wrote; The residual oil remaining from water flooding is a potential target for selective reservoir plugging of porous rocks. Bacteria plugging may occur by either shear multiplication of the number of bacteria or by the generation of polymer in-situ. These micro-organisms or products (polymer), selectively plug the undesired zone in the reservoir or higher permeability zones (Islam et al. 1990). As this occurs fluid is diverted into smaller pores causing an increase in fluid velocity within them. Clostridium acetobutylicum and Bacillus licheniformis produce acids and gases that modified pore structure (pore enlargement due to acid dissolution of carbonates and pore throat reduction due to biomass plugging) in the laboratory core analysis of the technology. As verified by test conducted by Public health laboratories, MEOR processes are considered environmentally friendly. They reported that the mixed culture of bacterial is safe to handle, and poses no threat to plants, animals or human beings. In fact the microbes in MEOR are simply hydrocarbon utilizing, non-pathogenic due to their natural occurence in petroleum reservoirs, hence are safe for plants, animals, and humans (Bryant et al, 2004)

Application of Microbial Enhanced Oil recovery Method

Microbial enhanced oil recovery (MEOR) method will work in most reservoirs or wells if properly applied and monitored. Since 1993 two thousand five hundred (2500) wells have been treated in Lake Maracaibo.

Through a careful and continuous record-keeping of data collected from the thousands of treated wells, it has been determined that the organisms as living creatures have their range of maximum efficiency in conditions within their environment limitations. In vast majority of reservoirs, the conditions present are: Temperature: Between 150^0 and 220^0 Fahrenheit, Pressure: Less than 20,000 psi, Salinity: Between 25-30% and Water and sediment percentage, less that 60%(Simon et al. 2006). Basically there two methods of application of the method, which are Endogenous and Exogenous Injection

In the endogenous, specific Nutrients are injected into the reservoirs or fields to stimulate the growth of indigenous micro-organisms. In North West Alabama, Prof. Lewis Brown was able to extend the life of a field by seventeen years through the injection of special nutrients to feed indigenous micro-organisms and the field produced additional 400,000 barrels at the cost of 11.3 per barrel of new oil. Also the Titan process injects a non-glucose nutrient formula into the reservoir and this non-glucose nutrient source induces the micro-organisms to become “active” in the reservoirs by changing the characteristics of their skin. The microbes then seek and surround oil droplets in the sand stones and Carbon strata. This activity dislodges and breaks up oil droplets, which significantly increases oil recovery (Brown, 2002).

Exogenous injection of micro-organisms into wells or reservoirs. In this method of MEOR application, the micro-organisms strains are isolated or selected from the aquifer underlying the reservoir. The strain is then cultured and injected in to reservoir as pure, mixed or even adapted cultures. During the period of injection a complete growth medium containing all major nutrients necessary for the microbial growth is also injected to feed the micro-organisms injected to enable them survive, replicate and off course produce the desired metabolites.

From the above discussion, and the factors that influence micro-organisms growth and metabolisms discussed microbial creatures will survive the conditions prevailing in most reservoirs. MEOR can be applied to single wells, to well systems, to entire reservoirs, to well with gas-lift and operating, to water injection wells etc. (Advanced Technologies, C.A 1998).

Materials Used and Data Acquisition

The materials used to carry out this investigation were; Core samples, Fluids (Water, Brine, Microbes-nutrient solution, and Crude). Core samples were obtained from some fields in the Niger Delta region in Nigeria and the microbes were cultured at the microbiology laboratory in the University of Port Harcourt. The experiments were performed at partially simulated reservoir conditions of

Figure1. The six core plug samples

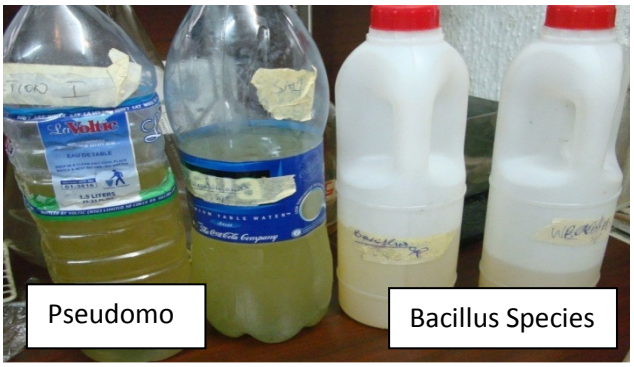

Figure2. Micro-organisms in nutrients broth

Figure3. Fluid Samples

the fields in which the cores where obtained. The core samples, brine, microbes in both nutrient broth and mineral salt solution and the equipmental setup for the core flooding experiment used are representedby: Figure 1, Figure 2, Figure 3 and Figure 4 respectively. Also, the data obtained from the core samples are shown in Table 1 and Table 2.

Flow test experiments

The basic aim of the experiment is to determine the extent to which the organisms can further reduce the residual oil saturation of the core samples already pre-flooded to residual oil saturation by conventional water flooding. Each core was inserted into the rubber sleeve with both ends tightly fitted with end stems (inlet and outlet) and loaded onto the core holder that contained water under a pressure of 2000 psi (assumed or simulated reservoir over burden pressure) at ambient temperature. Next, the fluids, oil and brine were put in both chambers of the accumulator, connected to the constant flow rate pump and the plug through the flood head and end stem.

The core was flooded to a new brine saturation (irreducible or connate water saturation) using the Bonny light crude at oil break - through. The process was

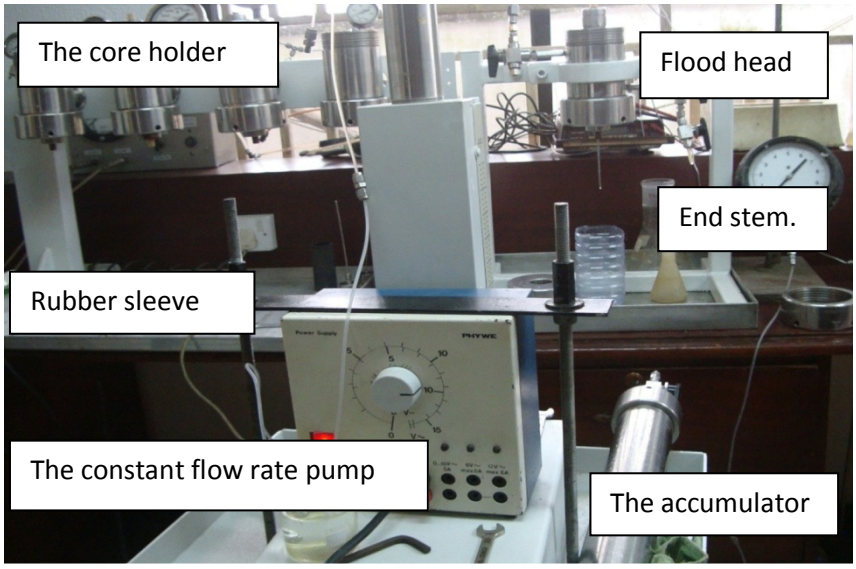

Figure 4. Equipment setup for core flooding experiment

Table 1: Pore Volume Determination

S/N	CORE CODE	DRY Wt(gm)	SATURATED Wt(gm)	BRINE Wt(gm)	PERCENTAGE SATURATION	PORE VOL.(cm^3)	EXPECTED BRINE Wt(gm)
1	Sample1	108.651	131.27	22.62	95.9806	23.2878	23.5673
2	Sample2	118.11	132.96	14.85	88.2091	16.8254	17.0273
3	Sample3	124.85	145.31	20.46	142.6056	14.1772	14.3473
4	Sample4	103.63	117.65	14.02	93.2354	14.8588	15.3473
5	Sample5	119.02	134.75	12.73	96.4646	16.1131	16.3065
6	Sample6	125.16	140.60	15.48	92.7944	16.6825	16.8822

Table 2. Core Porosity and Permeability Determination

Core sample	Length (h) in cm	Diameter (d) in cm	Area (A) in cm^2	Bulk volume (V_b) in cm^3	Pore volume (V_p) in cm^3	Porosity	AIR PERM (mD)	LIQUID PERM (mD)
Sample1	6.10	3.20	10.7535	65.5965	23.2878	0.3550	3120	6706.84
Sample2	5.80	3.70	10.7535	62.3703	16.8254	0.2698	5180	2139.52
Sample3	6.00	3.80	11.3426	68.0556	14.1772	0.2083	6640	2639.79
Sample4	5.40	3.60	10.1801	54.9725	14.8588	0.2703	5950	1370.34
Sample5	5.50	3.80	11.3426	62.3843	16.1131	0.2583	3900	1822.41
Sample6	5.70	3.80	11.3426	64.6528	16.6825	0.2580	2769	1444.05

continued for twice the pore volume which is 46cm^3 in the first plug (Core sample 1) until no further brine was produced. Volumes of brine displaced by oil were recorded and assumed to be the initial oil in place in the reservoir. In order to mimic a depleted reservoir model, the system was flooded back to residual oil saturation

Table 3. Results obtained from flow tests

Core Plug No	INOCULUM TYPE	V_{bi} (cm^3)	V_{bd} (cm^3)	V_{rd} (cm^3)	V_{pwf} (cm^3)	V_{sw} (cm^3)	V_{pmf} (cm^3)	V_{rwf} (cm^3)	V_{oc} (cm^3)	V_t (cm^3)
Sample 1	B in MS	23.288	14.2	14.2	7.2	9.088	0.54	7.0	6.8	7.4
Sample 2	P in MS	16.825	8.4	8.4	4.8	8.425	0.42	3.6	3.18	5.22
Sample 3	B in NB	14.177	13.1	13.1	7.0	1.077	1.8	6.1	4.3	8.8
Sample 4	P in NB	14.859	10.0	10.0	5.1	4.859	1.3	4.9	3.6	6.4
Sample 5	B&P in NB	16.113	10.4	10.4	6.2	5.813	2.4	4.2	1.8	8.6
Sample 6	B&P in NB	16.445	11.2	11.2	5.3	5.245	1.6	5.9	4.3	6.9

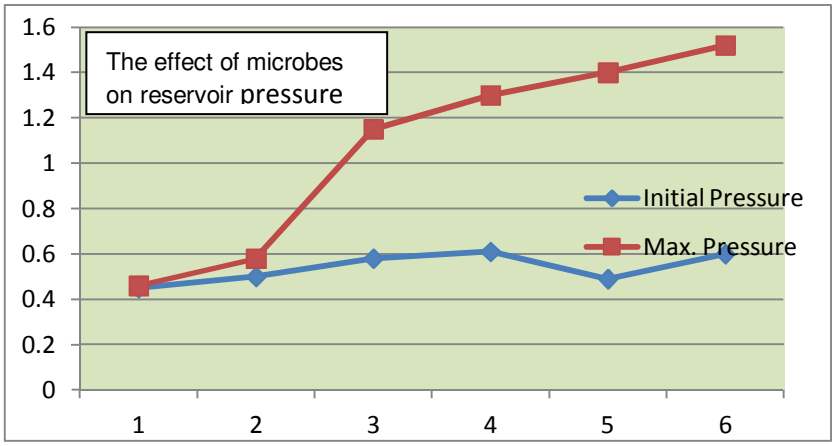

Figure 5: Effect of microbes on reservoir pressure

Table 4. Conditions and results from shut-in runs

Core samples	Microbe	Amount (cc)	Shut in period (hrs)	Initial pressure (psi)	Maximum pressure (psi)
Sample 1	B	10	48	0.45	0.46
Sample 2	B	15	48	0.50	0.58
Sample 3	P	10	48	0.58	1.15
Sample 4	P	15	48	0.61	1.30
Sample 5	B & P	10	48	0.49	1.40
Sample 6	B & P	15	48	0.60	1.52

with brine until water breakthrough occurred. For this study, because there are no naturally occurring energies inherent in the reservoir model, both primary and secondary recovery schemes is embedded in the flooding to obtain irreducible oil saturation with respect to brine. The experiments were carried out in five stages which were: Core saturation with brine, Oil injection to space, brine injected back to deplete the simulated reservoir, injection of microbes plus nutrient rich solution to recover the remaining oil, product obtained for the tertiary recover.

RESULTS AND DISCUSSION

The results obtained from the flow test experiments are

Table 5. Conditions and results from shut-in runs

Core samples	Bacteria solution Type	Volume (cc)	Shut-in period (hrs)	Viscosity Before test (cp)	Viscosity After test (cp)
Sample 1	B	10	48	0.41	-
Sample 2	P	10	48	0.41	-
Sample 3	B	10	48	0.41	0.350
Sample 4	P	10	48	0.41	0.344
Sample 5	B & P	10	48	0.41	0.330
Sample 6	B & P	15	48	0.41	0.328

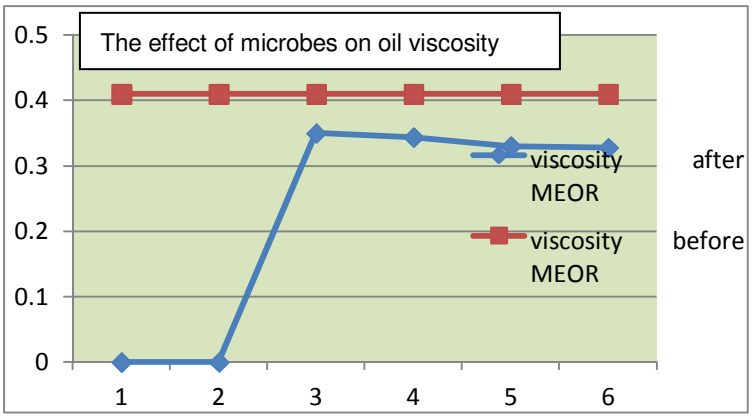

Figure6. Effect of microbes on oil viscosity

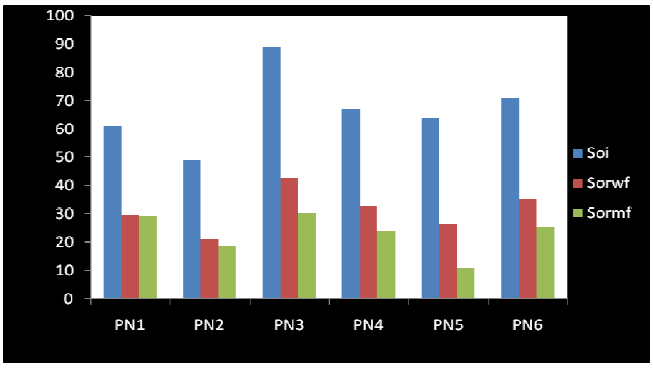

Figure 7**.** Chart showing oil saturations in core samples at the different stages

given in Table 3. Column four was determined from the second stage of the experiment where dead crude was passed through the flood head to the core sample to displace the initial single phase system of brine. This is the volume of brine recovered as effluent from stage two as illustrated above. Column 5 is observed to be same volumes as column B, because it was deduced based on the assumption that there is no void age created at any point of the flow test in this study. That is to say that the oil immediately occupies the space that the displaced

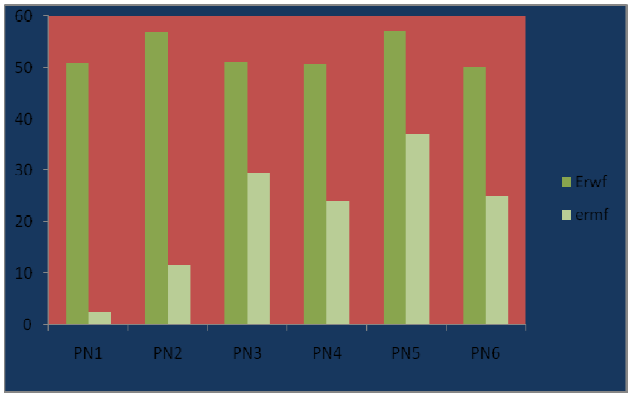

Figure8**.** Chart showing recovery efficiencies of water flooding and microbial flooding**.**

brine provides, hence the assume potion that the same volume is original oil in place for each core sample. Column 6 is the volume of oil recovered during water flood at the third stage of the experiment. Column 7 is the connate or irreducible water volume, gotten by subtracting the oil in place from the pore. Since the values of Vrd were all the volume of brine that could be produced after oil break through occurred, it means the volumes of brine that will remain in the core for all practical purposes is Vsw. The oil volumes recovered after micro-organisms have introduced and allowed to incubate for 48hours is Vrmf. Vrmf is residual oil volumes after primary, secondary recovery scheme. Initial oil in the core sample, less, the volume produced by flooding. Finally, is the volume of the critical oil still left in the core even after the microbial enhanced oil recovery (MEOR) application.

Figure 5 and Figure 6 show the tests results obtained from the shut in experiment in order to see the effect of the bacterial culture used (bacillus and pseudomonas) on the pressure in the reservoir model and viscosity of the crude oil. The effects are given in Table 4 and Table 5 respectively. The maximum pressure attained due to bacteria activity was recorded. In each experiment, the microbial solution was flown into the reservoir model through an electrically operated constant flow rate pump after 48hrs.

Figure 7 and Figure 8 show the saturations as percentages of pore volume are presented from the volumes of fluids recovered from each stage of the experiment as shown above.

CONCLUSION

The significant differences established in the results of the first runs; sample 1 and sample 2 where the micro-organisms nutrient medium was mineral salts, and those of sample 3 - sample 6 core samples with nutrient broth as nutrient medium indicates clearly that nutrient type determines the performance of this method. Comparing Sorwf andSormf values from charts we notice a substantial reduction in residual oil saturations, the classical sense of all EOR methods therefore, this MEOR method will work in Niger Delta reservoirs. From the residual recovery efficiencies due to microbial flooding, percentage Ermf of sample 5 was the maximum.

Recommendation

From the observations made, results obtained and consequent analysis, the following are recommended.

1. Nutrient broth is a more suitable nutrient medium to grow and maintain the production of expected or deserved metabolites and microbial population.
2. Mixed cultures of two or more organisms is more effective to obtain more bio-products and consequently better results.
3. All the literatures reviewed suggests that clostridium acetybulum, a purely anaerobic microbe be used to obtain copious gas production and eliminate the fear of possible death of the organisms due to lack of O2.
4. To overcome the problems of adaptation of organism, I recommend that nurturing indigenous micro-organisms with richer nutrients be considered in field applications.
5. Also, since the process led to a reduction in the viscosity of the recovered oil, its recommend also that the method will be efficient for heavy oil recovery.

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