The Petro-Bioreactor: Changes to Reservoir Fluids and Environment

Specifically selected microbes form a Petro-bioreactor in the porous reservoir rock, migrating outward from the wellbore. As they metabolize portions of the crude oil the result is improved oil recovery and beneficial bi-products.

The selected microbes are cultured from naturally occurring species, are friendly to the environment and are not regulated by the EPA. They are motile, seeking out their food source. As they degrade the normal alkanes in the crude oil, the long-chain molecules are cracked into short-chain solvents. Beneficial side products include carbon dioxide, hydrogen, alcohols, fatty acids, biosurfactants and biopolymers. Oil viscosity is reduced. Paraffin wax precipitation problems are reduced. API oil gravity is increased. Scale forming ions are removed from water and scale is inhibited. Sulfate reducing bacteria are controlled. Production and reserves are increased while operating problems are reduced.

Figure 2: Microbes Degrading Solid Wax (long-chain alkane molecules)

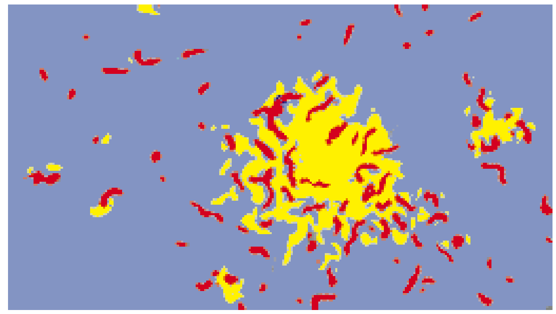


Figure 1: The Petro-Bioreactor in the Porous Rock

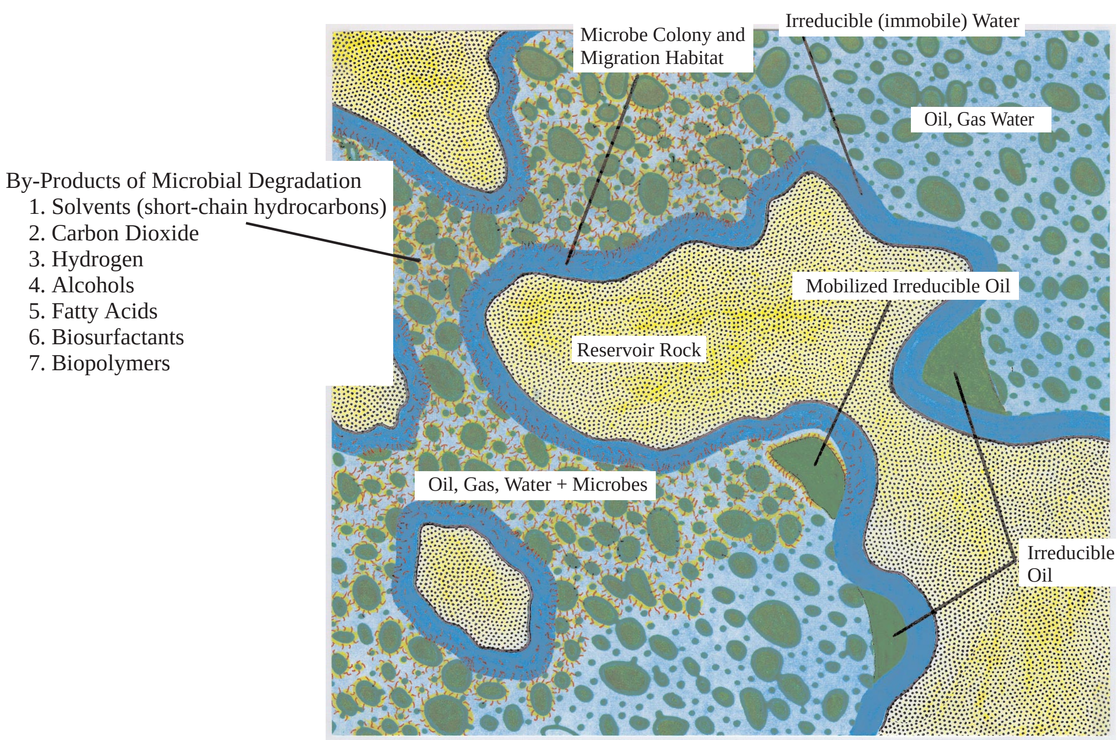


Table 1: Changes in Oil Properties

Conventional vs. Microbe Enhanced

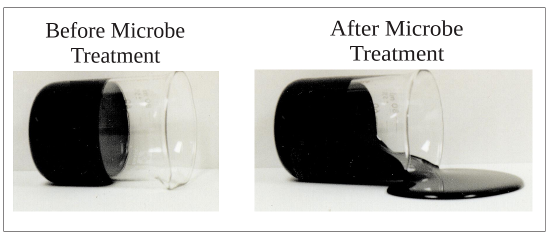
	Conven.	Enhan.
API Gravity	**39.4**	**41.9**
Viscosity (cp)	**15**	**9**
Pour Point (°F)	**98**	**81**
% Solvents *	**40**	**52**
% Paraffin Wax	**60**	**48**

* Solvents include gasoline, kerosene and diesel.

Changes that microbes make in some common crude properties are shown in Table 1.

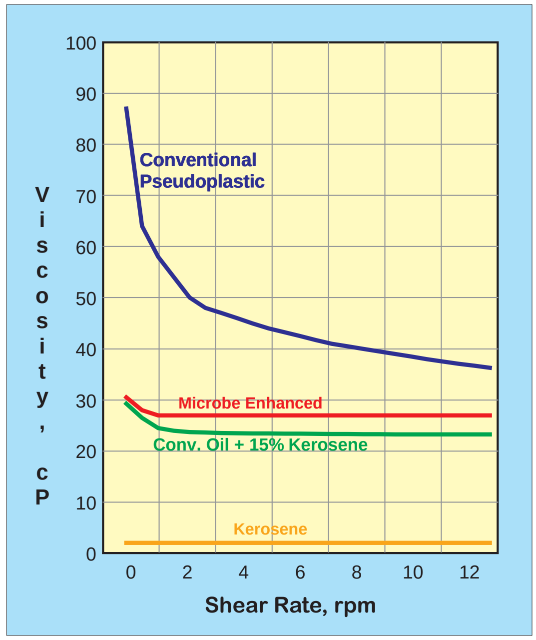
One obvious change made by the microbes is in pour point. Crude flows easier at the same temperature after treatment with microbes.

Figure 3: Pore Point Improvement



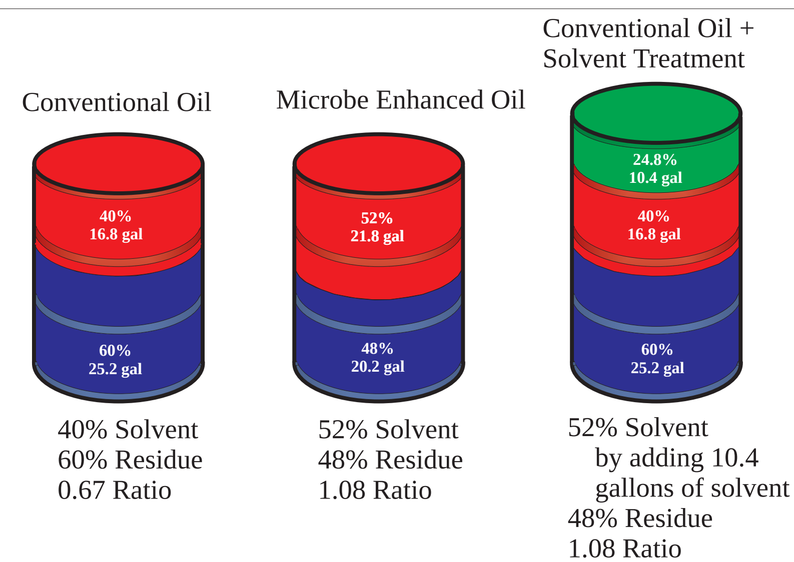
Viscosity of crude oil varies with shear rate. It is a pseudo plastic fluid, unlike water and kerosene for which viscosity is nearly constant as the shear rate is varied. By reducing the content of long-chain molecules, microbes shift the crude toward a more Newtonian fluid, as shown in Figure 5.

Figure 5: Newtonian Index



The affect microbes have on the crude is similar to adding solvent. The oil is thinned and moved toward a Newtonian fluid simi-

Figure 4: Oil Enhancement — Higher Solvent Content



larly as if kerosene had been added. As the long chains are degraded, volume increases and density decreases:

$$C_{18}H_{38} \rightarrow 2C + C_8H_{18} + C_6H_{14} + C_2H_6$$

$C_{18}H_{38}$ weighs 7.6 lbs./gal.

2C reduces weight 0.4 lbs./gal. to 7.2 lbs./gal.

. 50% C_8H_{18} at 5.9 lbs./gal. = 0.61 gal.

38% C_6H_{14} at 5.6 lbs./gal. = 0.48 gal.

12% C_2H_6 at 3.1 lbs./gal. = 0.29 gal.

$\therefore$ 7.2 lbs = 1.38 gal. $\rightarrow$ 5.2 lbs./gal.

The microbes break this long chain molecule by removing two carbon atoms.

Figure 6: ASTM Distillation

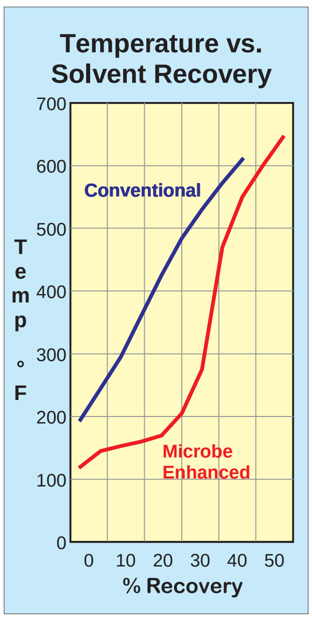
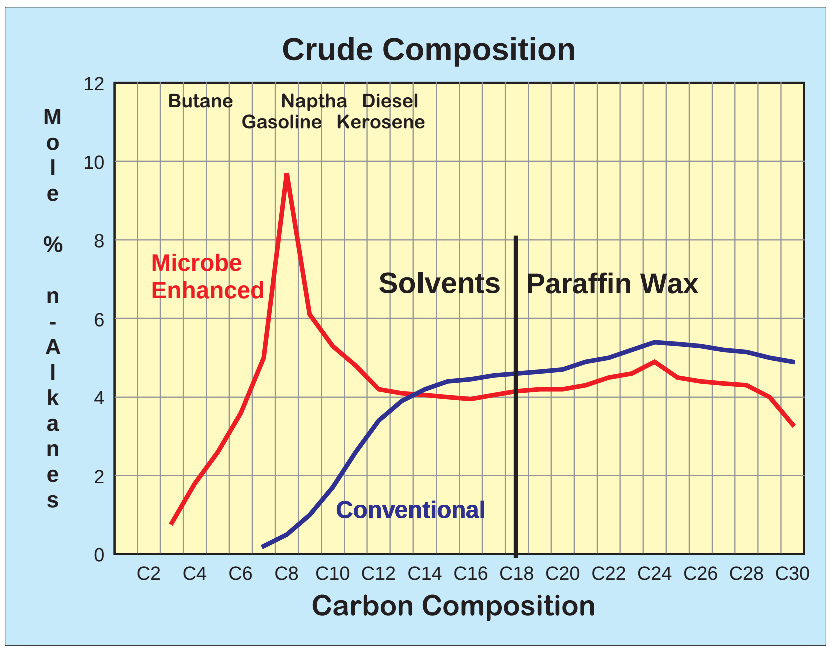


Figure 7: Gas/Liquid Chromatograph



The shift in molecular composition of the crude is proven by ASTM distillation analysis and gas/liquid chromatography.

For the ASTM distillation, the recovery is greater at the same temperature indicating a shift toward more volatile components. This shift is confirmed in the chromatograph. The n-Alkane composition is shifted to the lower length carbon chains. As the food source is degraded, the microbes can no longer find nourishment until the enhanced crude is produced bringing un-degraded crude to the microbes, or the microbes move to "fresh" food. Microbes significantly and beneficially alter the properties of crude oil.

Microbes, Inc.'s technology further alters the reservoir environment by removing scale forming ions from formation water. In addition, the bioproduction of organic acids and proteins have chelating, anti-precipitation and biosurfactant properties. Most common oil field scales are inhibited including calcium carbonate, calcium sulfate, iron sulfide and barium sulfate. Scale is made more soluble in the formation water and the microbes work to remove any protective paraffin layers. Microbes, Inc.'s scale control is a complete water treatment program — the removal of metallic ions, solubilization of scale deposits and inhibition.

Microbes, Inc.'s Anti-Microbic Suppression (AMS) technology is an environmentally friendly and user safe treatment process that controls SRB contamination of production and injection wells, producing reservoirs and surface facilities. AMS interferes with SRB colonization by reducing nutrients, restricting colony space and destroying cell bodies.

Microbe Selection and Monitoring of Petro-Bioreactor

Oil and water samples are taken from the well head before and during microbe treating. Our lab test procedure is to inoculate each sample with different products and compare viscosity vs. shear rate changes to an un-inoculated control sample. The testing procedure takes about 14 days to com-

$$\text{Newtonian Index} = fn\left(\frac{\text{Viscosity of the Control}}{\text{Viscosity of the Inoculate}}\right)$$

$$= \frac{\text{control vis. @ min. shear rate} - \text{control vis. @ max. shear rate}}{\text{inoculate vis. @ min. shear rate} - \text{inoculate vis. @ max. shear rate}}$$

plete. The following parameters are determined from testing.

The Newtonian Index indicates the shift in molecular composition from a plastic (heterogeneous) liquid towards Newtonian (homogeneous) liquid. This index is used to recognize shifts in molecular composi-

$$\text{delta Viscosity} = \frac{\sum \text{control vis.} - \sum \text{microbe inoculated vis.}}{\sum \text{control vis.}}$$

tion caused by different microbe blends.

$$\text{EOR Index} = \frac{1}{1 - \text{delta Viscosity}}$$

The value is of less importance than the physical shape of the curve.

>= 0.10 for a positive test

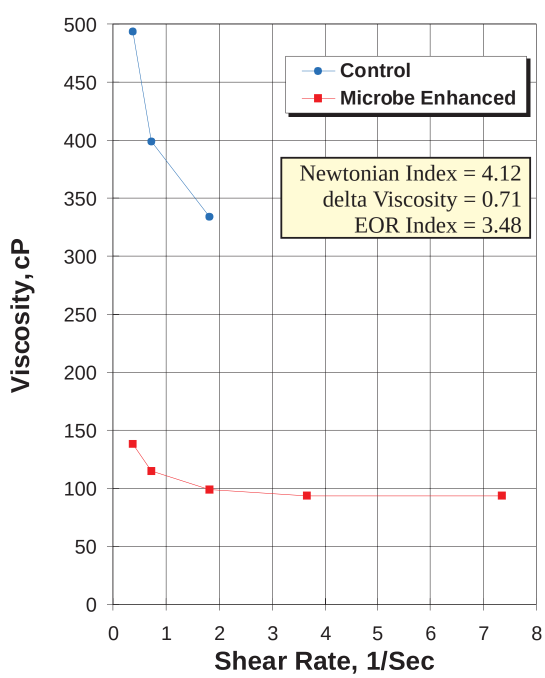
>= 1.15 for a positive test

The parameters are qualitative numbers used to estimate the effectiveness of our technology. Criteria for successful microbe enhancement are based upon empirical data developed based upon more than seven years of experience.

The test on the conventional oil is used to determine the blend of microbes used to establish the Petro-bioreactor. Also, after MMEOR is begun, subsequent samples are compared to the base sample to determine the degree of enhancement and if the microbe blend needs to be adjusted. These tests together with production and operating data allow ongoing monitoring of the effectiveness of the Petro-bioreactor.

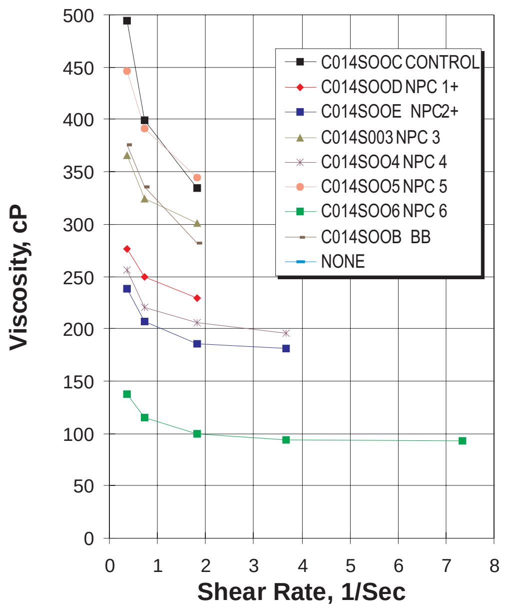
Figure 8 shows the change in viscosity that is typical of a crude high in paraffin. Figures 8, 9 and 10 are for a conventional crude oil. The well has not been treated and the crude has not been enhanced down-hole by a Petro-bioreactor. Viscosity for this sample is reduced 71% and the slope of the curve

Figure 8: Viscosity vs. Shear Rate
Best Microbe Blend



is reduced 348%. Microbes have effectively altered this crude's properties in the laboratory. The pre-MMEOR sample also

Figure 9: Viscosity vs. Shear Rate
Microbe Blend Selection



Summary 4/28/96 7:58 AM Oil Samples at 120°F
Data Set: C014 S -- Huabei Oil Field

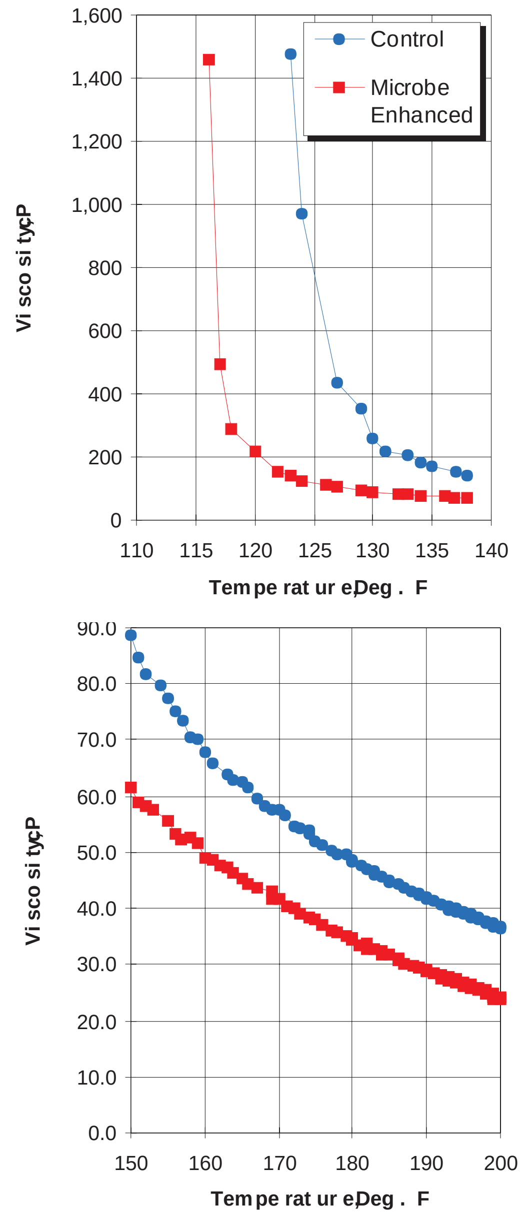
ID	Run Name	Newtonian Index	delta Viscosity	EOR Index
Control	C014SOOC CONTROL	1.00	0.00	1.00
1	C014SOOD NPC 1+	3.39	0.38	1.63
2	C014SOOE NPC 2+	3.05	0.49	1.95
3	C014S003 NPC 3	2.45	0.19	1.24
4	C014SOO4 NPC 4	3.20	0.44	1.80
5	C014SOO5 NPC 5	1.57	0.04	1.04
6	C014SOO6 NPC 6	4.12	0.71	3.48
7	C014SOOB BB	1.70	0.19	1.23

serves as a baseline against which actual field results are later measured.

The proper microbe blend is determined from the data presented in Figure 9, and a knowledge of how the different microbes interact. Effectiveness of different products is largely dependent on the crude's molecule size distribution. Microbes are selected that can best derive nourishment from the size molecules in this crude oil, thereby breaking the molecules into shorter chain lengths. Different strains of microbes working symbiotically in the Petro-bioreactor are are often more effective than a single strain in the laboratory.

The temperature curves in Figure 10 illustrate microbe induced reductions in cloud point and threshold viscosities. These

Figure 10: Viscosity vs. Temperature

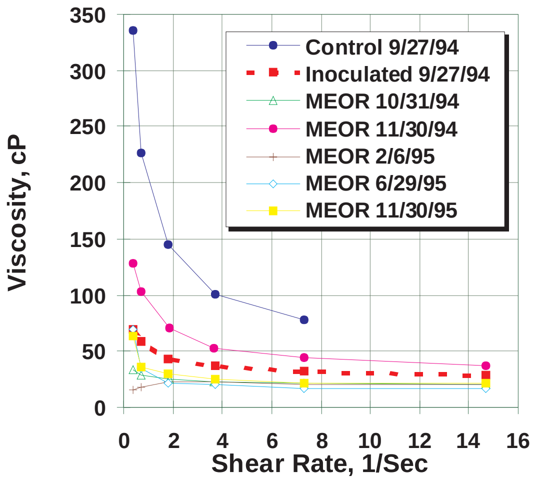


analyses are run on "dead" oil at atmospheric pressure so care must be taken in extrapolating the results to reservoir conditions. The value of these curves is to select proper microbes for treating and for a baseline to monitor the Petro-bioreactor.

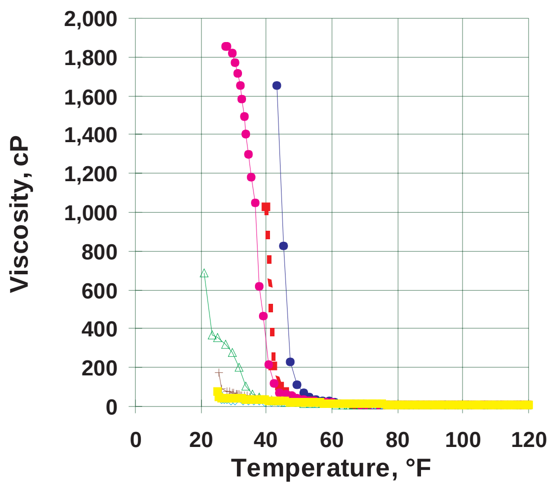
After MMEOR is begun, additional crude and water samples are taken and analyzed. These tests will show a downward viscosity shift for the un-inoculated MMEOR control compared to this conventional control. Also, inoculation will be ineffective at further lowering the viscosity if an effective Petro-bioreactor has already significantly improved the oil properties.

Figure 11: MMEOR Monitoring

(a) Viscosity vs. Shear Rate



(b) Viscosity vs. Temperature



The curves in Figure 11 illustrate the improvement in viscosity caused by the microbes in the Petro-bioreactor. The pre-MMEOR sample provides both a control and inoculated baseline against which samples taken over the next 14 months, after the start of MMEOR, are compared. In Figure 11(a) the viscosity versus shear rate curves indicate the microbes in the reservoir are indeed making the oil less viscous and more Newtonian. Figure 11(b) illustrates an even greater improvement in cloud point and threshold viscosity than was expected based on the pre-MMEOR inoculated conventional oil sample. This ongoing monitoring is used to optimize treatment frequencies and microbe blends.