
MMEOR: The Petro-Bioreactor

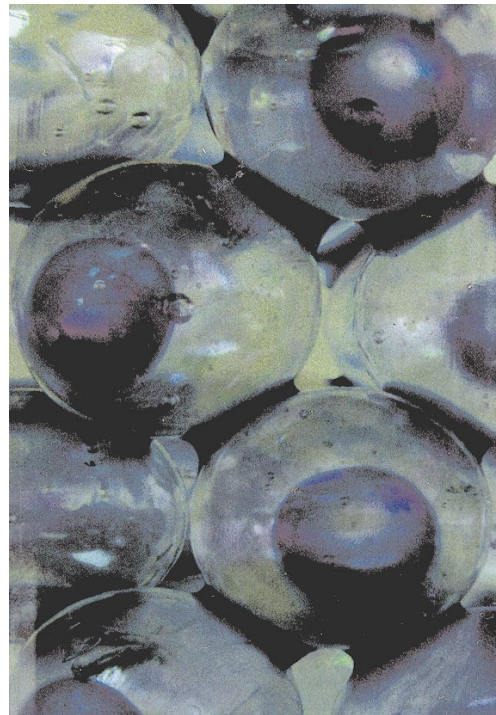
Oil producing formations can be transformed into very effective bioreactors. A bioreactor is a vessel or confined area whereby microbes can colonize and metabolize a food source passing or flowing through the reactor area. The combination of rock structure, flow characteristics and fluid composition are parameters necessary for biogenesis of hydrocarbons by anaerobic bacteria. Interconnecting pore spaces and rock matrix create the basic components required for bioreactors.

Oil bearing formations have large surface area to host or act as a habitat for microbe colonization. The maze of flow channels give retention and contact time between the food source and microbes. Water is required for microbe habitation and colonization and the fact water is the wetting phase in majority of oil reservoirs makes the water wet matrix rock ideal medium for a bioreactor. This wetting phase is immobile and continuous throughout the reservoir. This irreducible water medium provides a static environment for microbe colonization that is in constant contact with hydrocarbons percolating through the rock formation.

Figure 1 is an idealized representation of the distribution of wetting and non-wetting fluid phases about intergrain contacting glass spheres. This is a packing of glass beads that were initially flushed with water containing blue dye followed by flushing with mineral oil. This illustrates the water phase wetting and covering the rock matrix and creating the habitat for microbe colonization.

The non-wetting displacing oil phase is in contact with the water medium. This provides the physical requirement that hydrocarbons be in direct contact with microbes to metabolize and crack the saturated molecules as reservoir fluids flow or percolate through the porous media toward the well bore.

Figure 1: Wetting and Non-wetting Fluid in a Porous Media



The distribution in this illustration is primarily pendular, the wetting phase is not continuous about the spheres. This is caused by the large size of the glass beads. The grain size and radii of pore spaces in oil bearing formations are much smaller and the distribution is funicular, the wetting phase is continuous and completely covering the rock matrix.

Figure 2: Cast of Pore Space of Typical Reservoir Rock

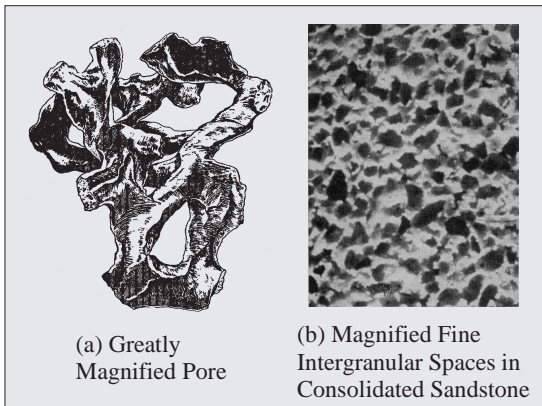


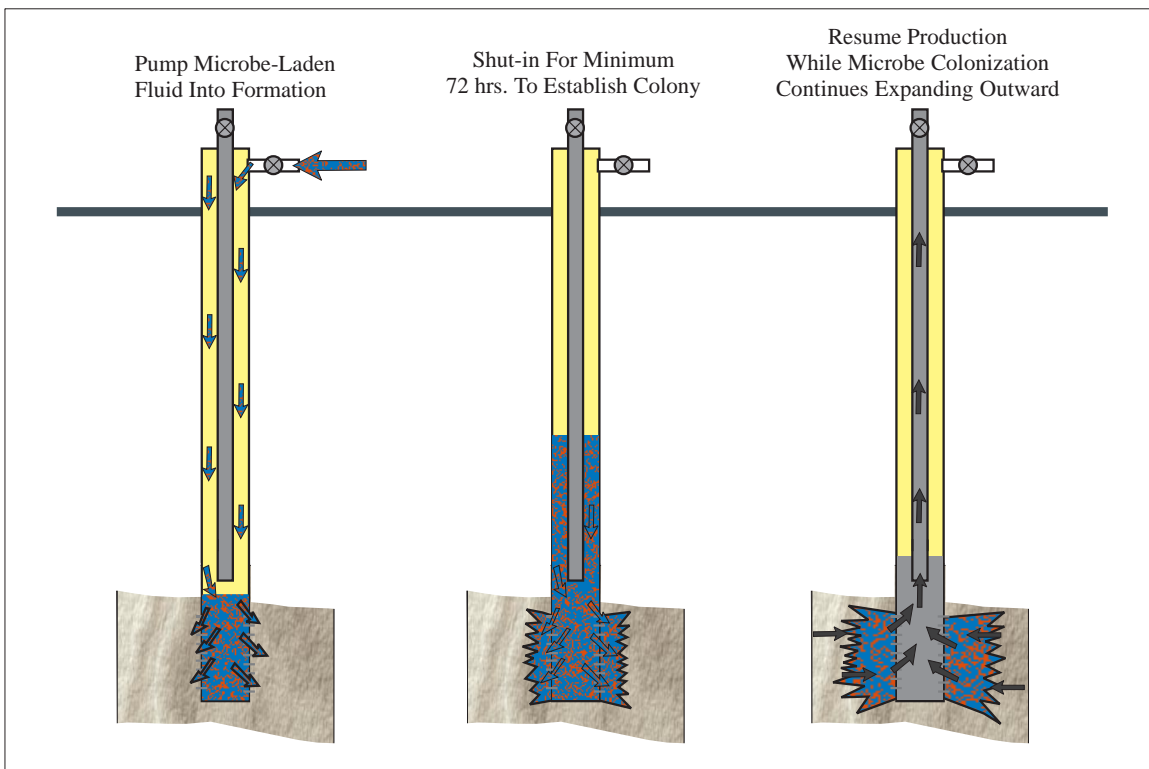
Figure 2 are castings of pore spaces in formation rock of consolidated sand. Figure 2(a) is greatly magnified and illustrates the varying size and shapes of pores and flow channels and the random connections. Figure 2(b) is less magnification and shows the maze of matrix rock and interconnected pore spaces characteristic of oil bearing formations.

Typical MMEOR procedure for establishing the Petro-bioreactor is to pump microbe laden fluid (formation or 2% KCl water) down the well bore and displace into the formation. The well is shut in to create static conditions to establish colonization in the water and most importantly the irreducible water wetting phase. Figure 3 illustrates the treating and colonization process.

Proper engineering and treatment design develops the formation into an effective Petro-bioreactor at near well bore and forces colony growth outward into the reservoir. The Petro-bioreactor treats hydrocarbons in place within the reactor area plus hydrocarbons entering the outer boundary and flowing through the Petro-bioreactor to the well bore.

Biogenesis of oil in-situ is a new technology developed by Microbes, Inc. The technology is a bridge between petroleum

Figure 3: Establishing the Bioreactor



physics and bioengineering. Because these two technologies are vastly different, misunderstandings and misconceptions exist about using microbes for production stimulation and enhance oil recovery. The following is a discussion of the three major areas of concern.

First concern: Is it possible for microbes to penetrate and migrate through formation rock?

Laboratory test has confirmed what is common place to Microbes, Inc.'s petro-bioengineering technology. Lab testing confirm that select bacteria can penetrate and pass through cores. It is not uncommon to measure rate of migration of fourteen inches per day. Several published studies prove bacteria completely migrates through cores tested including sandstones and limestones with permeability of less than 0.1 md.

Petroleum reservoir rocks vary so widely in composition, porosity, permeability and pore size distribution that it is impossible to make quantitative statements about degree to which bacteria penetrate fluid saturated rock. Some important qualitative observations have been made. Reservoir rocks with an appreciable fraction of pore volume composed of pores with minimum pore entry of 3 μm or more will permit the passage of large numbers of sulfate-reducing bacteria 0.6 x 3.0 μm in size without noticeable restriction. It is common knowledge sulfate-reducing bacteria have extensively penetrated many reservoirs throughout the world including tight sandstone and limestone formations.

Pore size distribution of sedimentary rocks vary from 0.1 to 50 μm in tight sands to 0.4 to 100 μm in medium coarse sandstone. The average size of MMEOR microbes are 0.2 x 3 μm . In comparison of pore size versus

microbe size, medium coarse sandstone has smallest pore diameter of two times and largest pore diameter of 500 times the size of MMEOR microbes.

Microbe selection is as important as adequate pore size. It has been determined that some microbes migrate through cores while others the same size do not. MMEOR microbes are mobile anaerobic bacteria selected and blended for their ability to migrate through cores containing saturated hydrocarbon. These microbes are specially blended to move about and seek reservoir oil as their sole source of carbon for growth.

Migration of microbes is through the immobile water wetting phase and occurs opposite direction of fluid flow. Although fluid flow can cause attrition and some interruption in microbe movement, the benefit of constant food source flowing in the reservoir stimulates migration and promotes Petro-bioreactor activity and MMEOR success.

Second concern: Can microbes survive and flourish in subsurface environments of high pressure and temperatures?

Microbes, Inc. has conducted extensive fluid testing to determine effects of subsurface conditions on microbe activity. A major part of MMEOR technology was developed from experimental testing using producing systems in the field.

The most important testing system is a hydraulic pumped well using produced water as power fluid. This system subjects microbes to high temperatures and pressures under dynamic conditions.

Microbes are exposed to 8000 psi pressure and estimated 4000 psi pressure drop across

the subsurface. The pumping action can be changed by regulating the pumping action at the surface pump. Pump design restricts pumping time of 24 to 55 minutes from discharge at subsurface pump to surface time. This is the bioreactor retention time.

Figure 4 is the schematic of one of the test systems used in Microbes, Inc.'s R & D program. The well is producing from 11,500 to 16,000 ft. and pumping from 10,500 ft. Reservoir temperature is 240° F, and temperature at the pump is 200° F. Microbe cultures are put into the system at the suction of the surface tri-plex pump and mix with the power water pumped into the well. The microbes mix with produced fluids at the subsurface pump and are pumped to the surface. The casing annulus is transformed into a bioreactor and oil is metabolized during the pumping time to surface.

Experimentation procedure is to inoculate the power water at the pump suction with

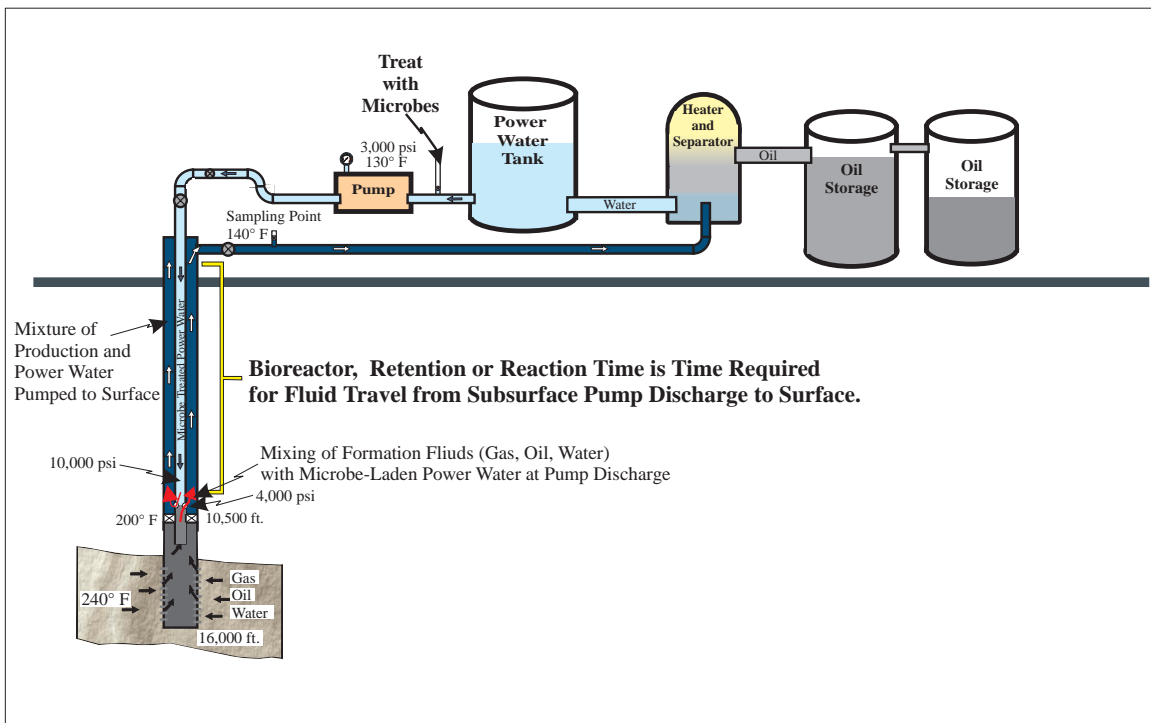
select microbes, pump down the well and back to surface. The returning fluid is samples and analyzed according to protocol to determine biological changes and effectiveness and petrophysical changes.

Microbes, Inc.'s testing has developed cultures to withstand the harsh environment and to be effective within the reaction time of the bioreactor. Minimum bioreactor retention time required to metabolize oil is 32 minutes. That is the time required to cause maximum viscosity reduction.

Third concern: Is there adequate retention time in the Petro-bioreactor to metabolize and crack reservoir oil flowing to the well bore?

Oil flowing in a reservoir is predominately in laminar flow. So much so that in many cases fluid movement is so slow that it is undetected by the human eye. This example

Figure 4: Field Testing and Developing Microbes for Petro-Bioreactor



illustrates the flow rate and retention time in an oil bearing formation.

Assume:

homogeneous reservoir rock

reservoir thickness, $h = 90$ ft.

porosity, $\phi = 20\%$

water saturation, $S_w = 30\%$

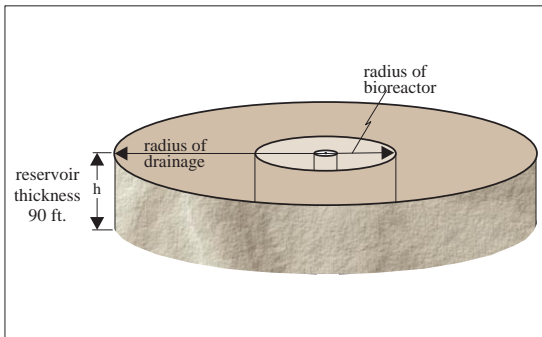
residual oil saturation, $S_{or} = 56\%$

formation volume factor, $B_o = 1.2$

recovery factor = 20%

petro-bioreactor radius, $r_b = 10$ ft.

Figure 5: Schematic of Reservoir Showing Petro-Bioreactor



Then the recoverable oil in place within r_b is

$$\frac{\pi \cdot r_b^2 \cdot h \cdot \phi \cdot (1 - S_w - S_{or})}{5.615 \cdot B_o} \text{ or } 117 \text{ STB.}$$

Assume the 117th barrel of oil produced is from the outer boundary limits of the Petro-bioreactor and the flow time and rate traveling to the well bore is the same as for oil entering from outside the Petro-bioreactor, flowing to the well bore. Then for a well producing 100 STB/day travel time to flow from r_b is

$$\frac{117 \text{ STB}}{100 \text{ STB/day}} = 1.17 \text{ days}$$

The average flow velocity through 10 feet of Petro-bioreactor is

$$\begin{aligned} \frac{10 \text{ feet}}{1.17 \text{ days}} &= 8.54 \text{ feet / day} \\ &= 0.35 \text{ ft./hr.} = 0.006 \text{ ft./min.} \end{aligned}$$

As shown by this graph, the time the oil is in the Petro-bioreactor increases rapidly as the microbe colony grows outward. The retention time increases from 1.17 days at $r_b = 10$ ft. to 30 days at $r_b = 50$ ft. to 120 days at $r_b = 100$ ft. The microbes have ample time to favorably alter crude oil properties.

Figure 6: Graph of Time in Petro-Bioreactor vs. Microbe Colony Radius

