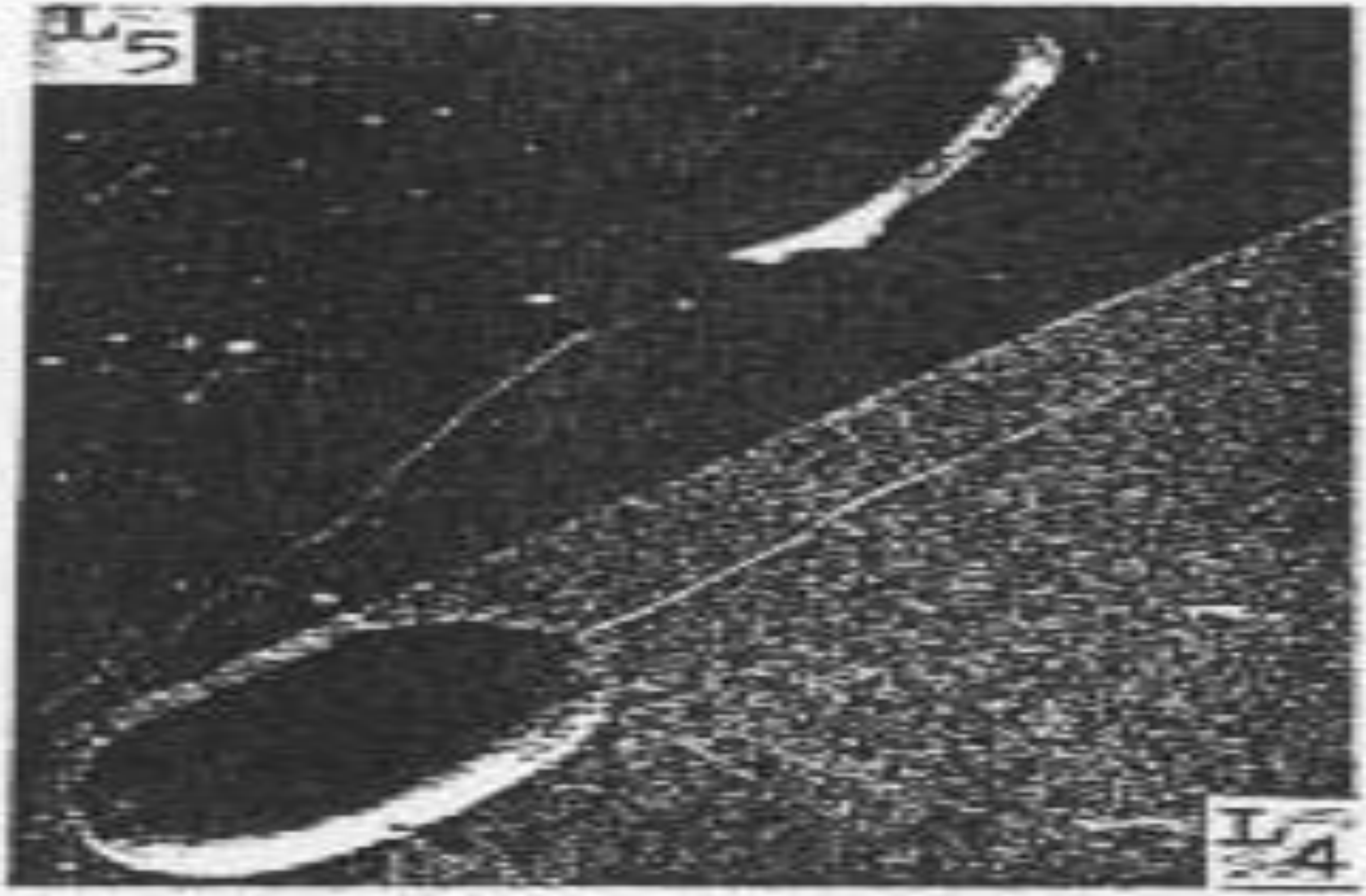
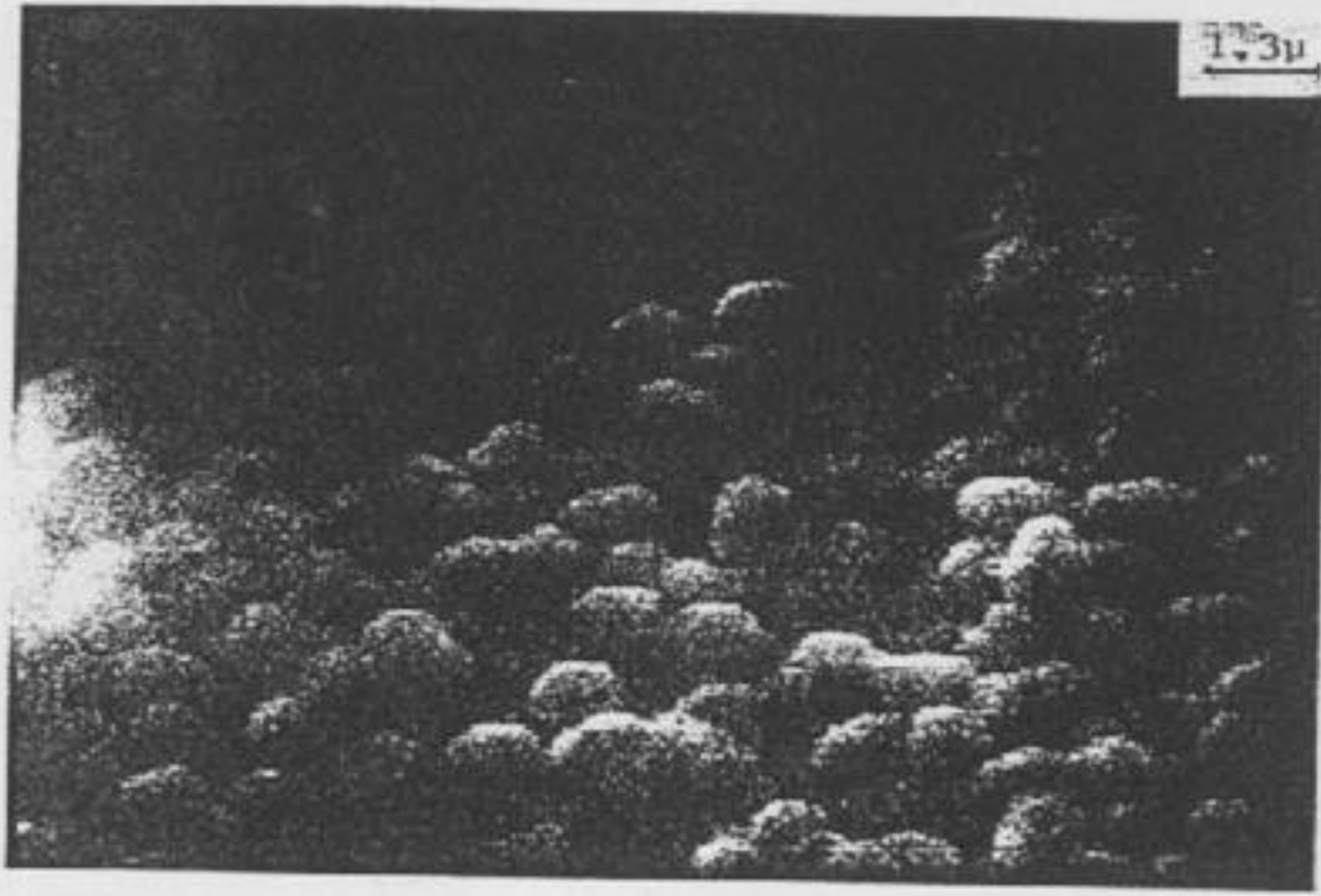
Special Purpose Reservoir Simulators

5-Bio-Chemical Simulators

Bio-Chemical Recovery

- **Microbial enhanced oil recovery (MEOR) technology is the process of introducing or stimulating viable microorganisms in an oil reservoir for the purpose of enhancing oil recovery.**


L5
L4

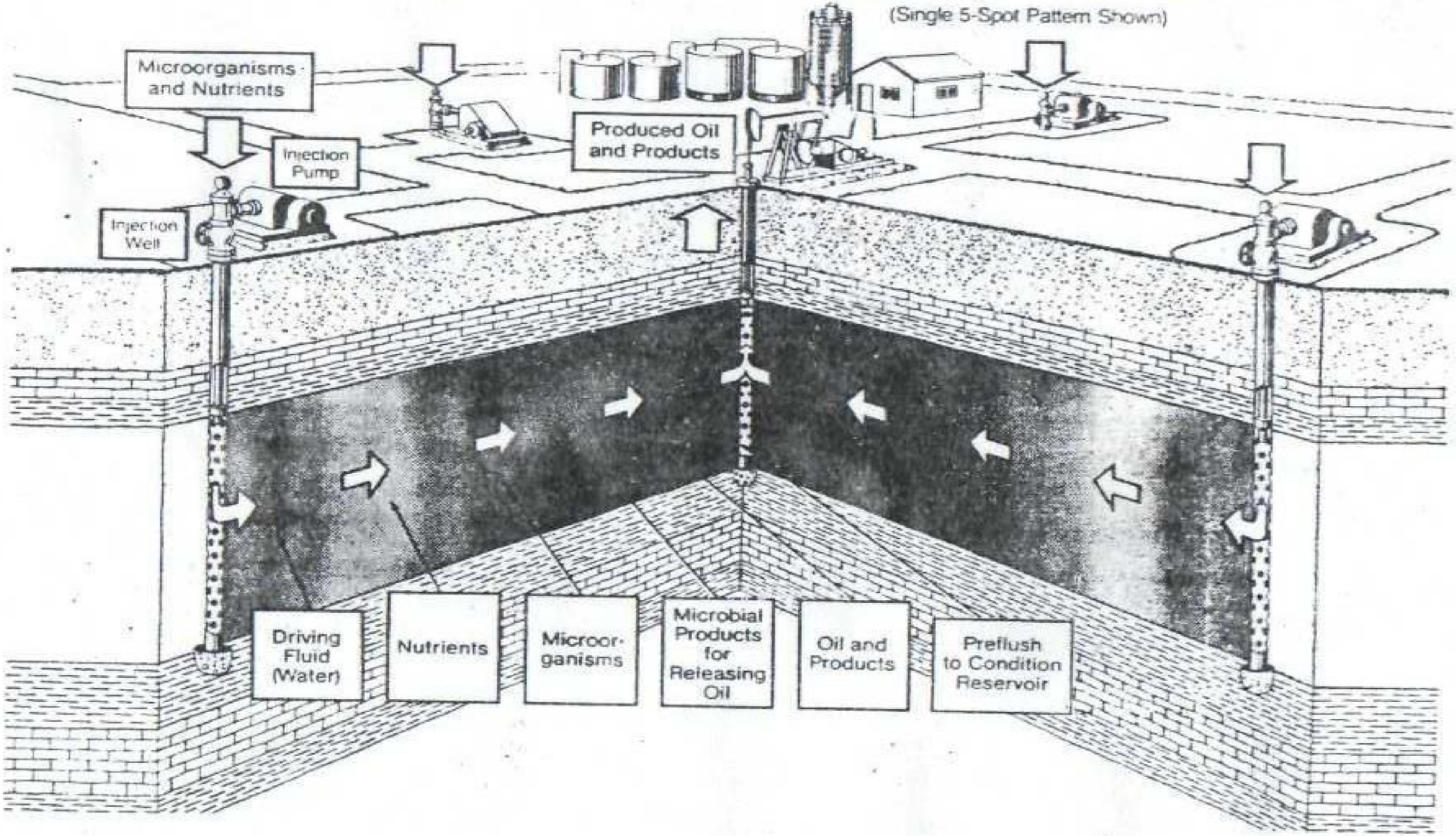

1.3μ


20KU X20,000 1μm


X20,000 1μm

MICROBIAL FLOODING

Recovery by this method utilizes the effect of microbial solutions on a reservoir. The reservoir is usually conditioned by a water preflush, then a solution of microorganisms and nutrients is injected. As this solution is pushed through the reservoir by drive water, it forms gases and surfactants that help to mobilize the oil. The resulting oil and product solution is then pumped out through production wells.



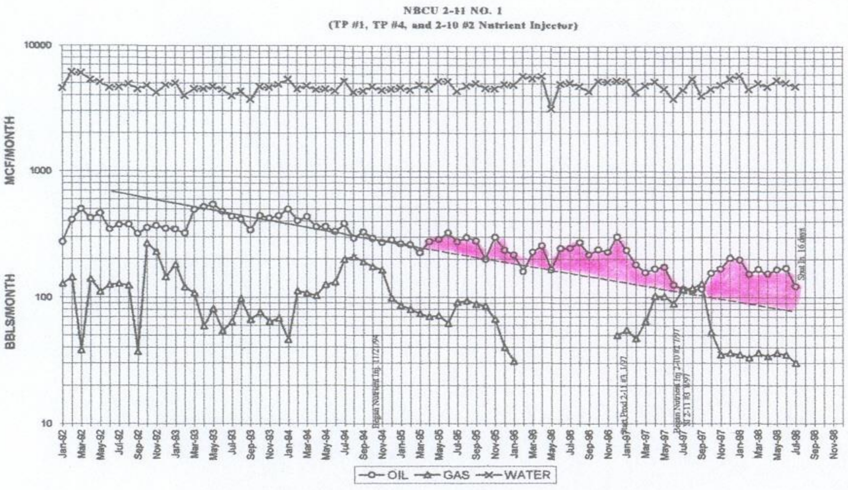


Figure 4: A production response began in this well about 5 months after starting nutrient injection in offset injector.

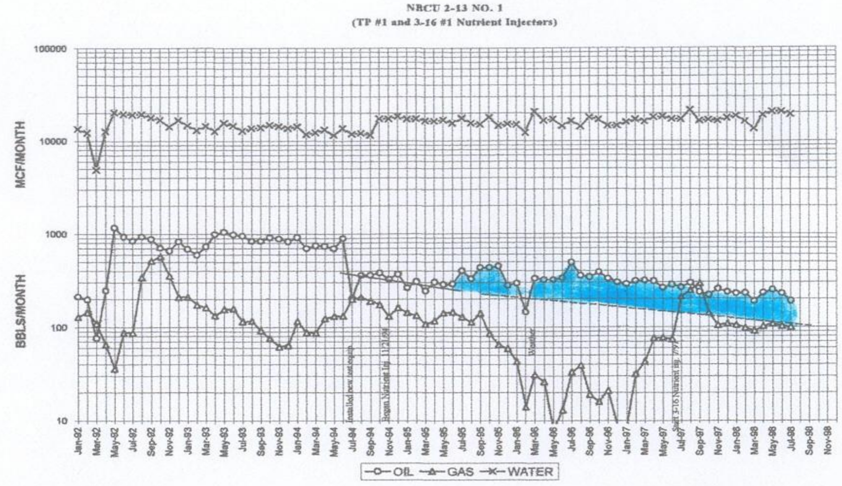


Figure 5: A significant production increase occurred about 7 months after starting nutrient injection in offset injector.

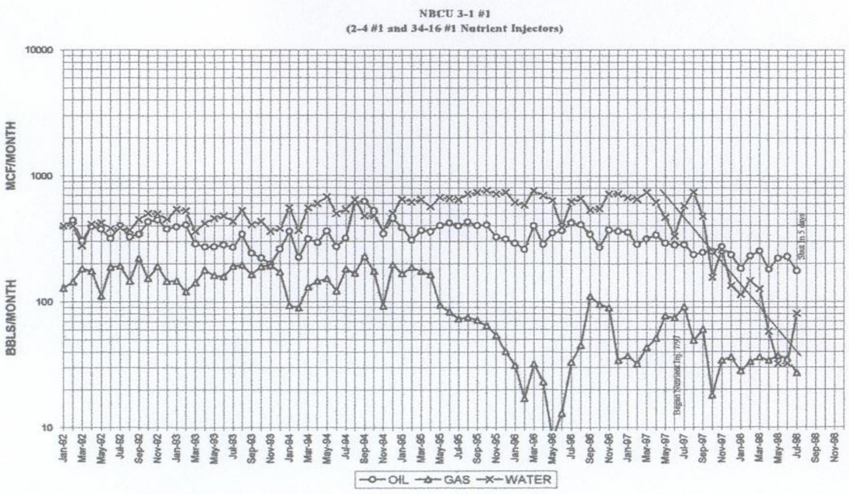


Figure 6: Note sharp decline in water production after 3 months of nutrient injection.

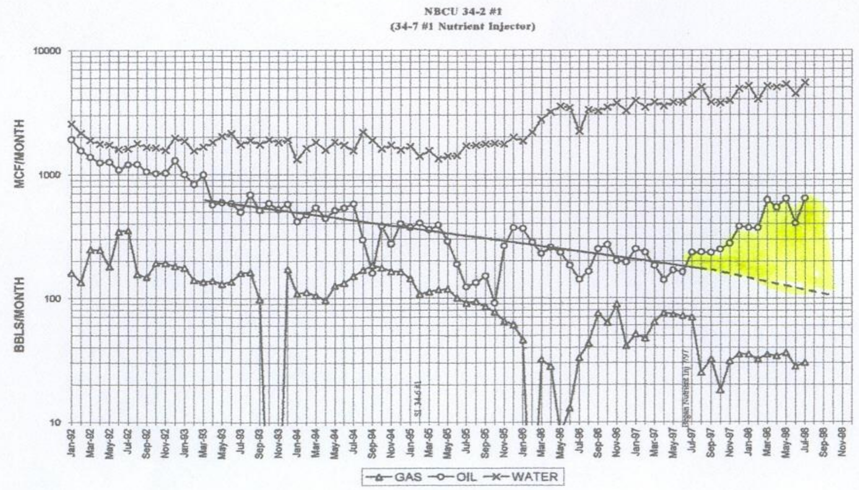


Figure 7: Production increased dramatically within 4 months of of starting nutrient injection in offset injector.

Compositional Simulators

- **Compositional reservoir simulators account for multiphase flow and interfacial mass transfer of each component in a hydrocarbon system.**
- **This implies that at any given time, the simulator tracks fluid movement and establishes the state of equilibrium of the reservoir fluids at the discrete points.**
- **At each node, phase pressure, phase saturation and overall composition are computed as a function of time.**

Basic Differential Equations for Flow in Reservoir Engineering

(Note: A similar approach is possible with energy and entropy equations)

Material Balance for One Component in One Phase

$$\frac{\partial}{\partial t}\left(\varepsilon_j \rho_j \omega_{ij}\right)+\vec{\nabla}\cdot\left(\rho_j \omega_{ij}\vec{u}_j-\varepsilon_j \vec{\vec{K}}_{ij}\cdot\vec{\nabla}\rho_j \omega_{ij}\right)=\varepsilon_j r_{ij}+r_{mij} \quad i=1,\ldots,N_C \quad j=1,\ldots,N_P$$

Summation $\sum_{j=1}^{N_P}(\ )$ leads to the Overall Compositional Equations; summation $\sum_{i=1}^{N_C}(\ )$ leads to the Phase Flow Equations.

Overall Compositional Equations

$$\frac{\partial}{\partial t}\left(\phi\sum_{j=1}^{N_P}S_j\rho_j\omega_{ij}+(1-\phi)\rho_s\omega_{is}\right)+\vec{\nabla}\cdot\left(\sum_{j=1}^{N_P}\left(\rho_j\omega_{ij}\vec{u}_j-\phi S_j\vec{\vec{K}}_{ij}\cdot\vec{\nabla}\left(\rho_j\omega_{ij}\right)\right)\right)$$

$$=\phi\sum_{j=1}^{N_P}S_j r_{ij}+(1-\phi)r_{is}, \quad i=1,\ldots,N_C$$

Phase Flow Equations

$$\frac{\partial}{\partial t}\left(\phi S_j\rho_j\right)+\vec{\nabla}\cdot\left(\rho_j\vec{u}_j\right)=\sum_{i=1}^{N_C}r_{mij}, \quad j=1,\ldots,N_P$$

Summation $\sum_{i=1}^{N_C}(\ )$ of the Overall Compositional Equations and summation $\sum_{i=1}^{N_P}(\ )$ of the Phase Flow Equations both lead to the Continuity Equation.

Continuity Equation

$$\frac{\partial}{\partial t}\left(\phi\sum_{j=1}^{N_P}\rho_j S_j+(1-\phi)\rho_s\right)+\vec{\nabla}\cdot\left(\sum_{j=1}^{N_P}\rho_j\vec{u}_j\right)=0$$

Note:

$\varepsilon_j=\phi S_j$ for fluids

$\varepsilon_s=1-\phi$ for solids

Special Cases of Phase Flow Equations

Phase Flow Equations

$$\frac{\partial}{\partial t}\left(\phi S_j \rho_j\right) + \vec{\nabla}\cdot\left(\rho_j \vec{u}_j\right) = \sum_{i=1}^{N_C} r_{mij}, \quad j = 1, \ldots, N_P$$

Buckley-Leverett

$$\varphi \frac{\partial S_w}{\partial t} + u \frac{\partial f_w}{\partial x} = 0$$

Diffusivity Equation

$$\nabla \cdot \left(\frac{k\rho}{\mu} \nabla \Phi \right) = \frac{\partial(\phi\rho)}{\partial t}$$

Liquid: $$\frac{\partial^2 P}{\partial r^2} + \frac{1}{r}\frac{\partial P}{\partial r} = \frac{\phi \mu c_t}{k}\frac{\partial P}{\partial t}$$

Gas: $$\frac{\partial^2 m(p)}{\partial r^2} + \frac{1}{r}\frac{\partial m(p)}{\partial r} = \frac{\phi \mu c_t}{k}\frac{\partial m(p)}{\partial t}$$

Laplace Equation

$$\nabla^2 \Phi = 0$$

Poisson Equation

$$\nabla^2 P = \text{constant}$$

Special Cases of Overall Compositional Equations

Overall Compositional Equations

$$\frac{\partial}{\partial t}\left(\phi\sum_{j=1}^{N_P} s_j\rho_j\omega_{ij}+(1-\phi)\rho_s\omega_{is}\right)+\vec{\nabla}\cdot\left(\sum_{j=1}^{N_P}\left(\rho_j\omega_{ij}\vec{u}_j-\phi S_j\vec{\vec{K}}_{ij}\cdot\vec{\nabla}\left(\rho_j\omega_{ij}\right)\right)\right)$$

$$=\phi\sum_{j=1}^{N_P} s_j r_{ij}+(1-\phi)r_{is},\qquad i=1,\ .\ .\ .\ ,N_C$$

Convection-Dispersion Equations

$$\phi\frac{\partial C_i}{\partial t}+u\frac{\partial C_i}{\partial x}=\phi K_{li}\frac{\partial^2 C_i}{\partial x^2},\qquad i=1,\ .\ .\ .\ ,N_C$$

Dispersion-Free Overall Compositional Equations

$$\phi\frac{\partial C_i}{\partial t}+u\frac{\partial F_i}{\partial x}=0,\qquad i=1,\ .\ .\ .\ ,N_C$$

Black-Oil Equations

$$\frac{\partial}{\partial t}\left(\frac{\phi S_j}{B_j}\right)+\vec{\nabla}\cdot\left(\frac{\vec{u}_j}{B_j}\right)=0,\qquad j=o,\ \mathrm{w}$$

$$\frac{\partial}{\partial t}\left(\phi\left[\frac{S_g}{B_g}+\frac{S_oR_s}{B_o}\right]\right)+\vec{\nabla}\cdot\left(\frac{R_s}{B_o}\vec{u}_o+\frac{\vec{u}_g}{B_g}\right)=0$$