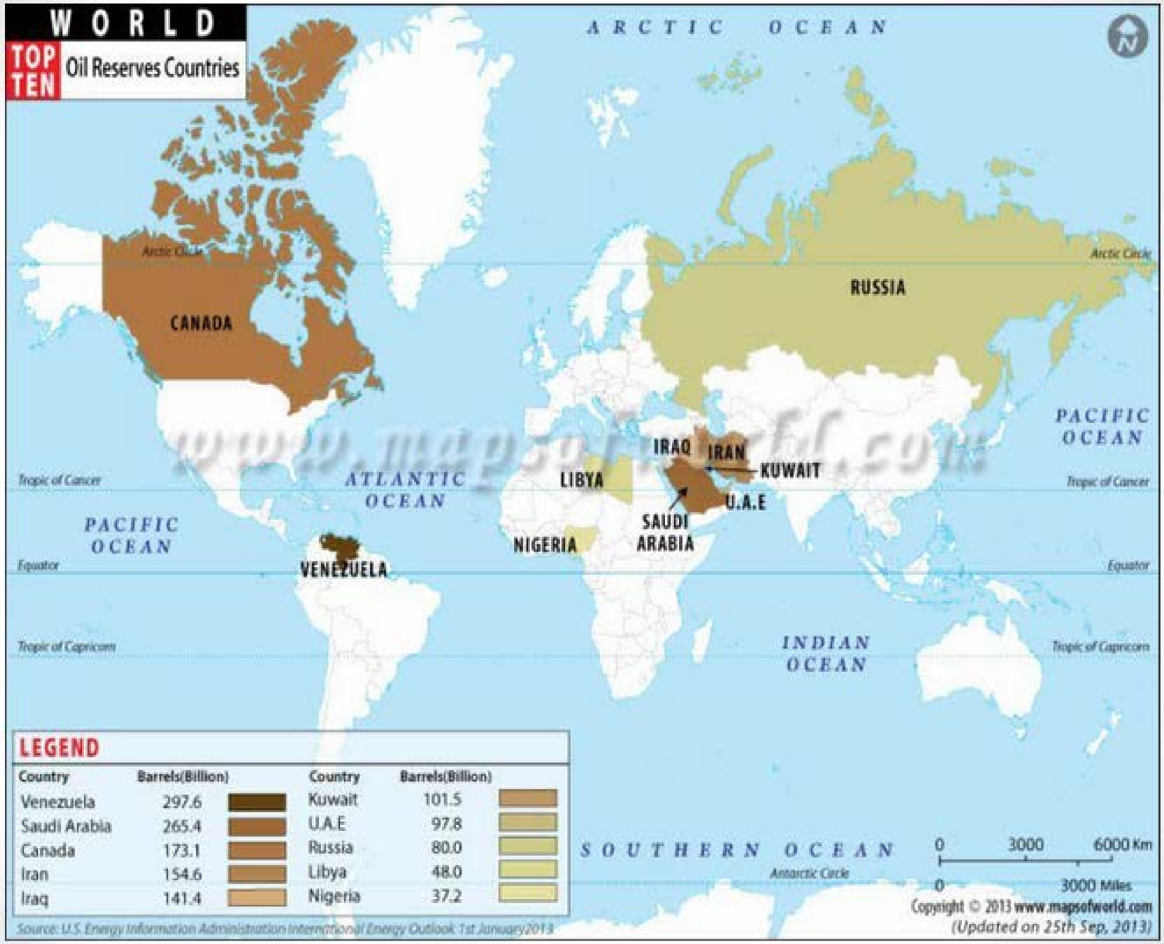
BIOTECHNOLOGY IN PETROLEUM RECOVERY: MICROBIAL ENHANCED OIL RECOVERY (MEOR)



RAMKRISHNA SEN

Department of Biotechnology

IIT Kharagpur

E-mail: rksen@iitkgp.ac.in; rksen@yahoo.com

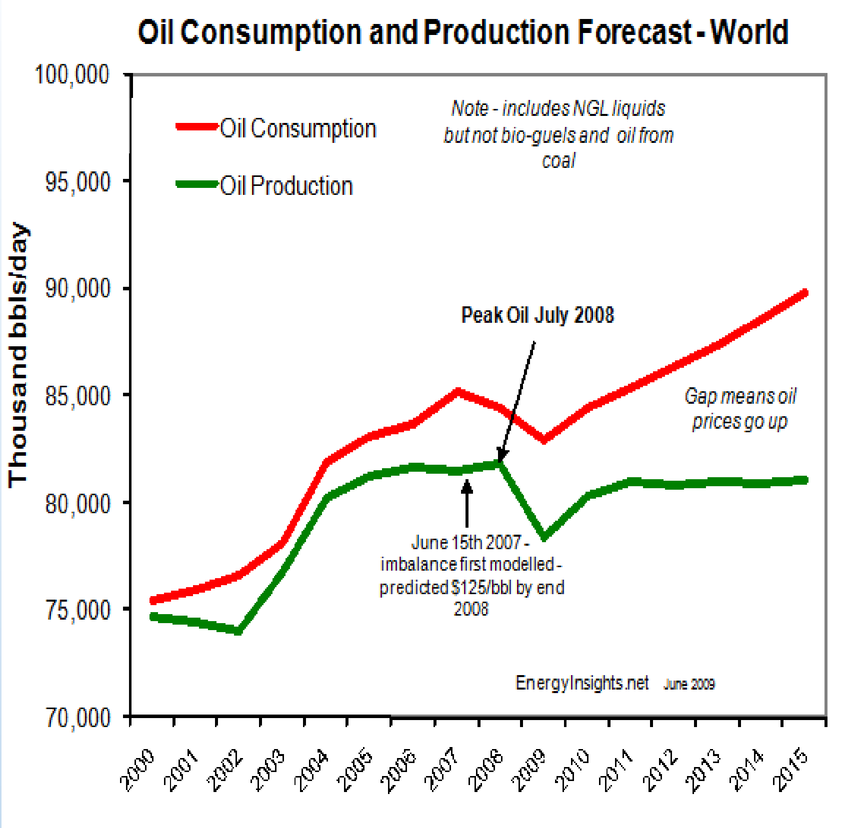
Introduction

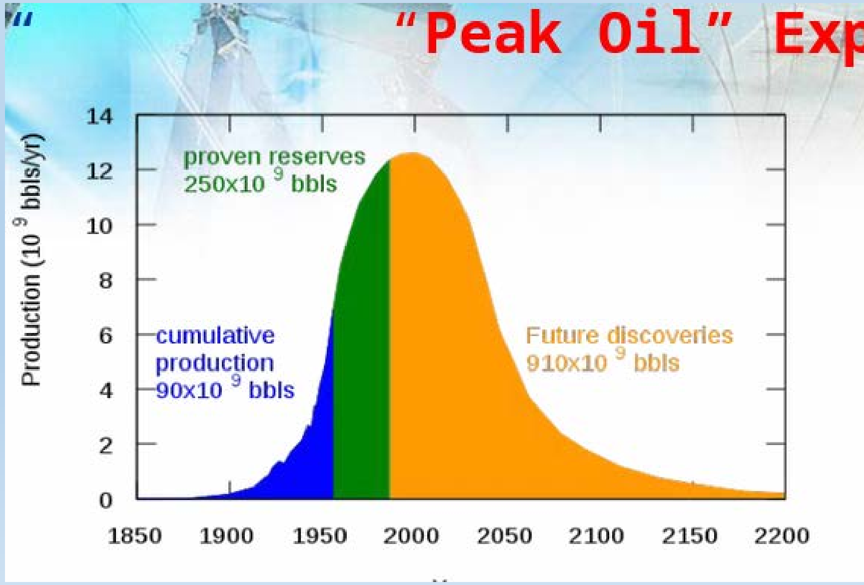
- Currently global energy production from fossil fuels is about 80-90% with oil and gas representing about 60 %

- During oil production, primary oil recovery can account for between 30-40 % oil productions

- While additional 15-25% can be recovered by secondary methods such as water injection leaving behind about 35-55 % of oil as residual oil in the reservoirs

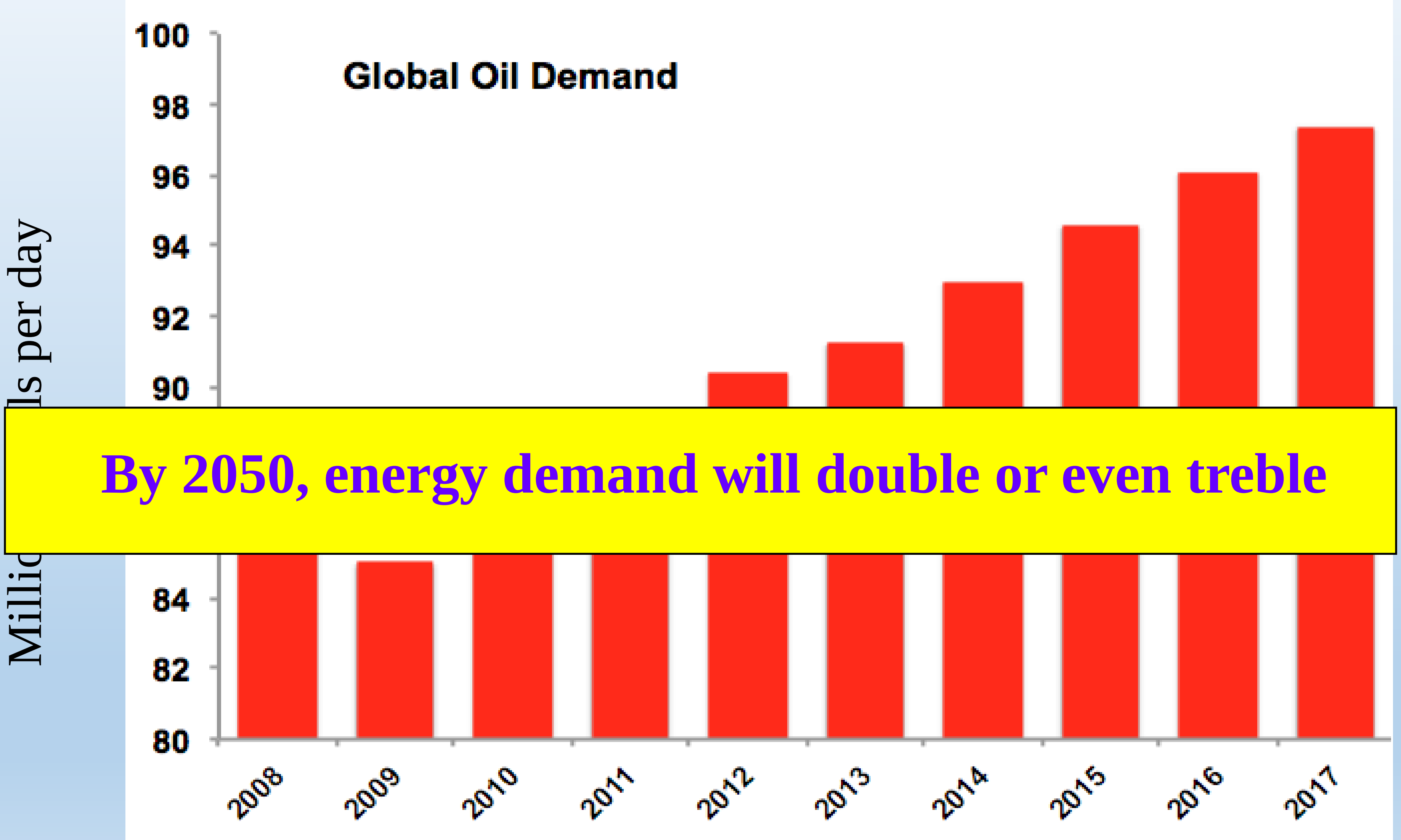
- This residual oil is usually the target of many enhanced oil recovery technologies and it amounts to about 2-4 trillion barrels (Hall et al., 2003)





Peak oil is the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline.

Global Oil Demand



By 2050, energy demand will double or even treble

Sources: IEA

Need for Enhanced Oil Recovery (EOR)

- When a new oil reservoir is drilled, the oil recovered is about 30-50% of the OIP and hence, there is still 50-70% oil left in the reservoir – **EOR Target**
- Application of EOR technology gives an additional boost to get out more oil from the reservoir, possibly about another 20 – 25%.
- Depleting oil reserves (Water cut > 90%) coupled with heavy dependence on oil imports mainly in Asia Pacific is expected to drive global EOR market.
- Global EOR Market is expected to reach USD 283 billion by 2020.
- Global EOR market volume was 2,681.6 million barrels in 2013 and is expected to exceed 16,000 million barrels by 2020, growing at a Compound Annual Growth Rate (CAGR) of ~30% from 2014 to 2020.

Sen, R (2008), Progress in Energy and Combustion Science, 34, 6, 714–724*

https://www.grandviewresearch.com/press-release/global-enhanced-oil-recovery-eor-market

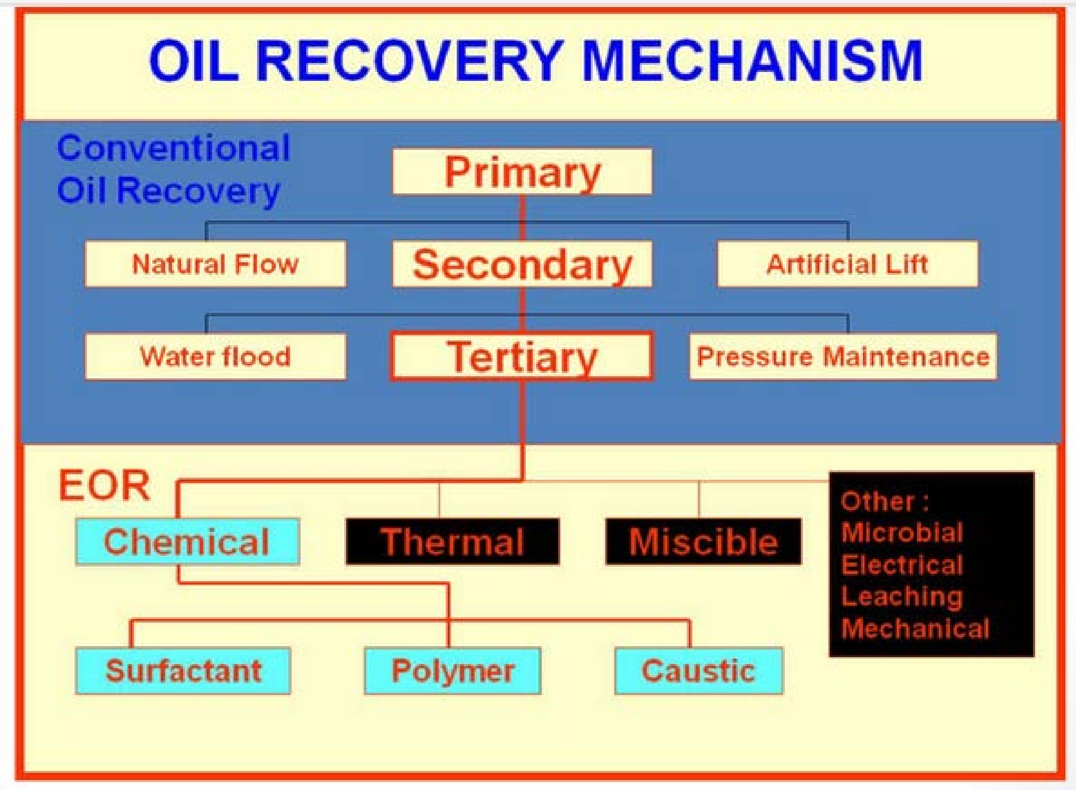
https://www.grandviewresearch.com/press-release/global-enhanced-oil-recovery-eor-market

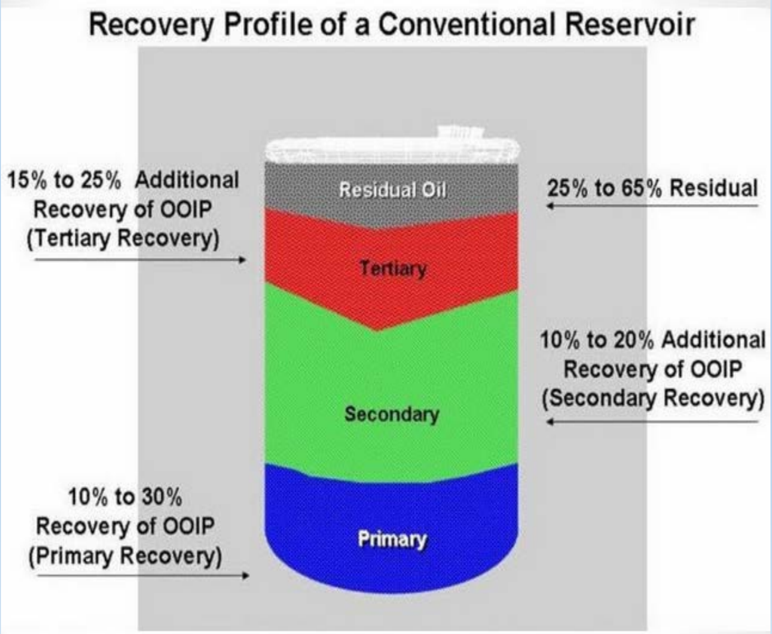
Patel……..& Sen (2015) Renewable & Sustainable Energy Reviews.,* **52**: 1539–1558.

Second and Third Generation EOR Methods

EOR methods are aimed to recover additional oil after primary recovery or natural drives in the reservoirs

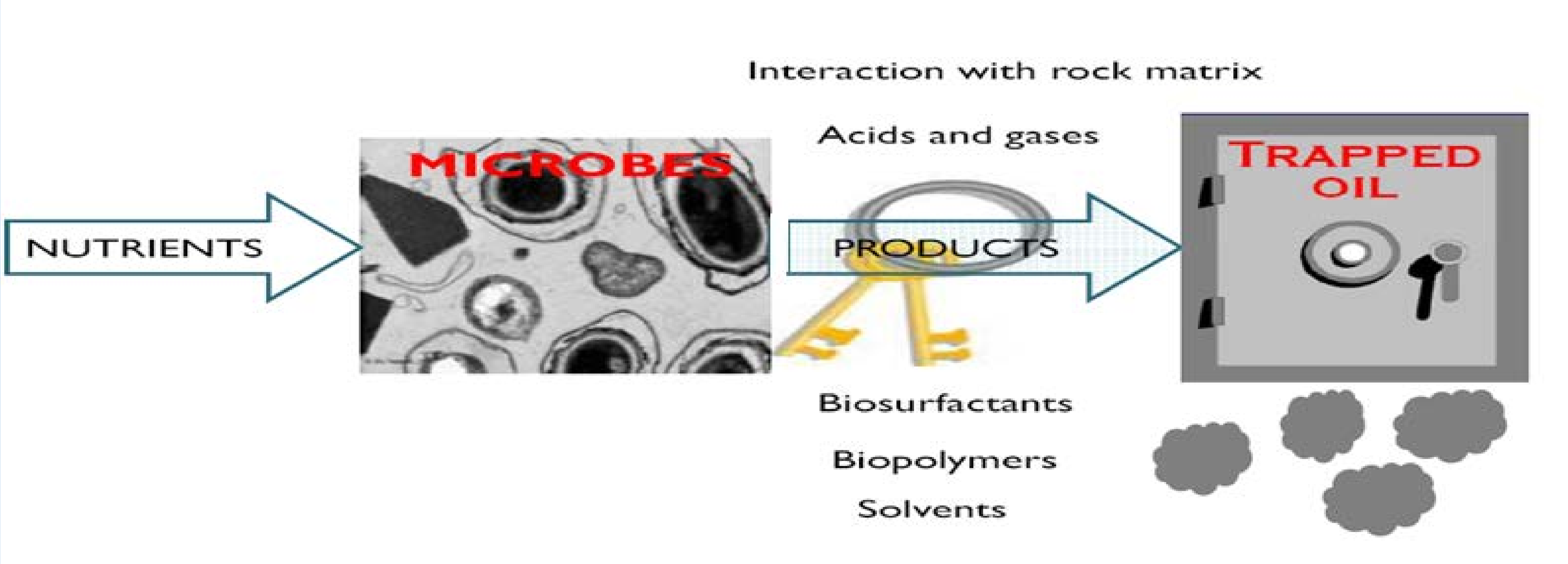
- Water flooding (water injection)
- Gas injection (not miscible)
- Carbon dioxide flooding (miscible)
- Steam injection and in-situ burning
- Surfacants or foams injection including Alkali-Surfactant injection
- Microbial Enhanced Oil Recovery Methods





What is microbial enhanced oil recovery (MEOR)?

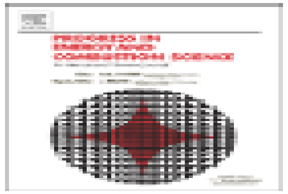
- Use of **microbes** to improve oil recovery, first proposed by Beckman in 1926
- How much additional oil can be produced? **Up to 60% oil in place after primary recovery**
- Two Types of MEOR process: ***Ex–situ* and *In–situ***



Progress in Energy and Combustion Science 34 (2008) 714–724

Contents lists available at ScienceDirect

Progress in Energy and Combustion Science

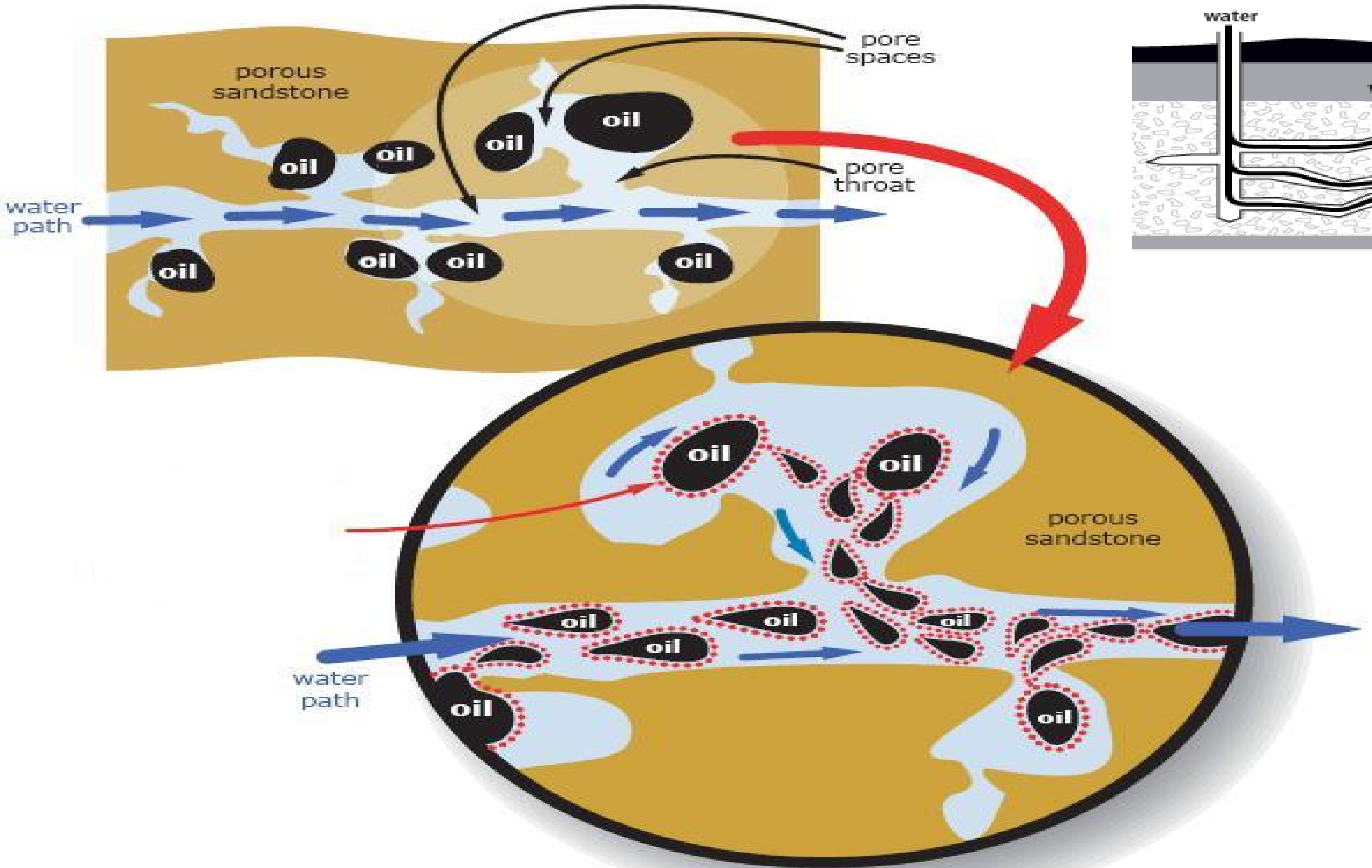


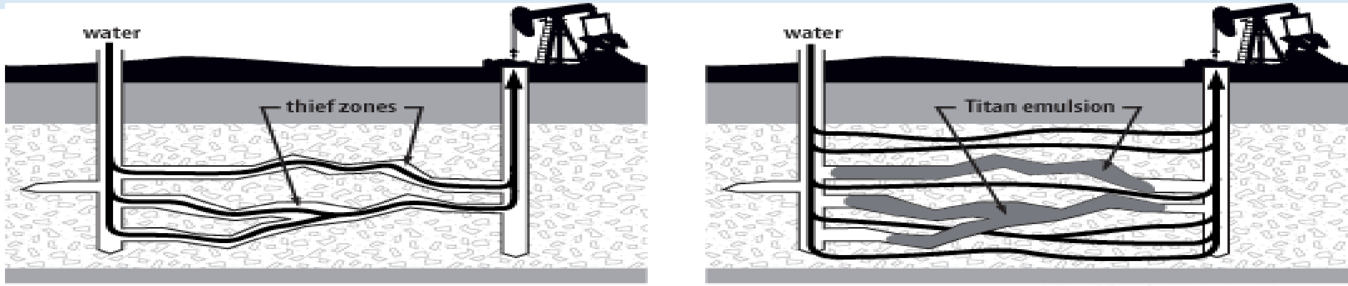
5-year Impact factor: 29.5; Citations: ~ 630

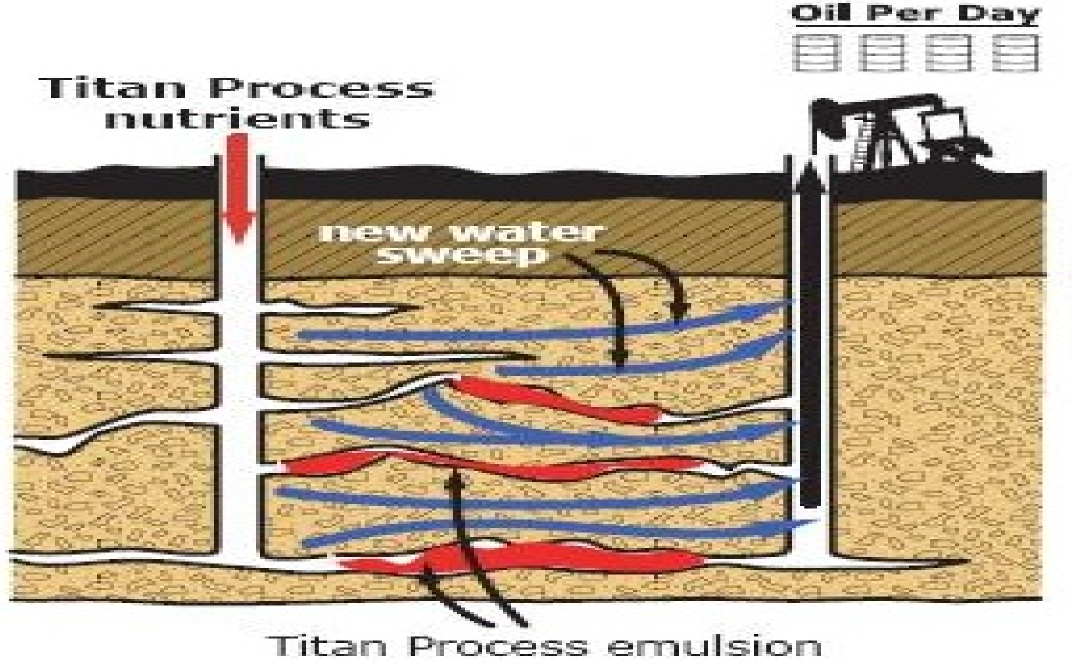
Biotechnology in petroleum recovery: The microbial EOR

Ramkrishna Sen *

Department of Biotechnology, Indian Institute of Technology (IIT), Kharagpur, West Bengal 721302, India







Review
TRENDS in Biotechnology Vol.24 No.11
Full text provided by www.sciencedirect.com
ScienceDirect

Towards commercial production of microbial surfactants

Impact factor = 21.94
Citations: 975

Soumen Mukherjee, Palashpriya Das and Ramkrishna Sen

Department of Biotechnology, Indian Institute of Technology, Kharagpur, West Bengal–721302, India.

Renewable and Sustainable Energy Reviews 52 (2015) 1539–1558

ELSEVIER

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

Impact factor = 15.9; Citations: 180

Recent developments in microbial enhanced oil recovery

CrossMark

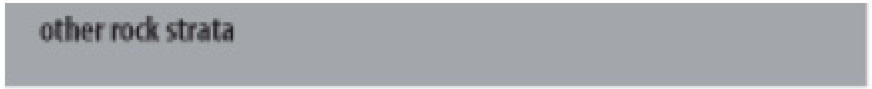
Jay Patel [a,1], Subrata Borgohain [b,1], Mayank Kumar [c,2], Vivek Rangarajan [c], Ponisseril Somasundaran [d], Ramkrishna Sen [c,*]

[a] Department of Bioengineering, University of California, Berkeley, United States
[b] Department of Petroleum Technology, Dibrugarh University, India
[c] Department of Biotechnology, Indian Institute of Technology Kharagpur, West Bengal 721302, India
[d] Langmuir Center of Colloids and Interfaces, Department of Earth and Environmental Engineering, Columbia University in the City of New York, NY 10027, United States

ENHANCED OIL RECOVERY (EOR): OPERATING MECHANISMS

1. ORIGINAL OIL FIELD:

Primary production is caused by internal reservoir pressures that have built up over millions of years. This pressure forces a flow of liquids towards the well bore which acts like a release valve. Years of oil production takes place and approximately 20% of the original oil in place is recovered.

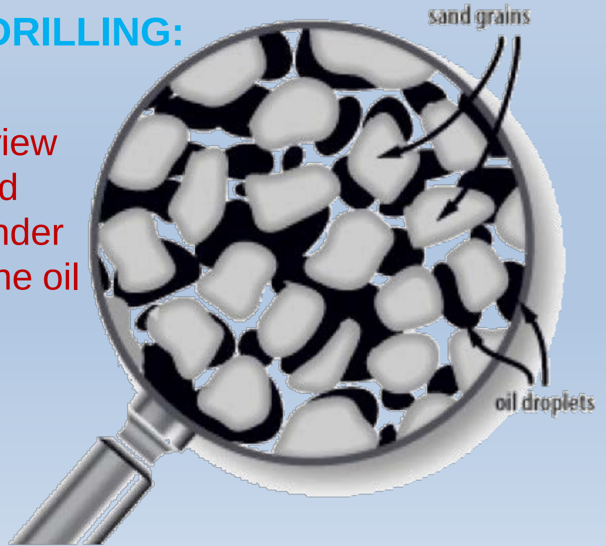


2. YEARS AFTER:

The pressure of the reservoir abates and recovery now has to be aided by forcing water under very high pressure into the reservoir that will push oil towards the production well. This is called a “water flood” and is the most common secondary oil recovery method. The water, pushing through the porous carbonate or sandstone, recovers another 10-15% of the original oil in place.

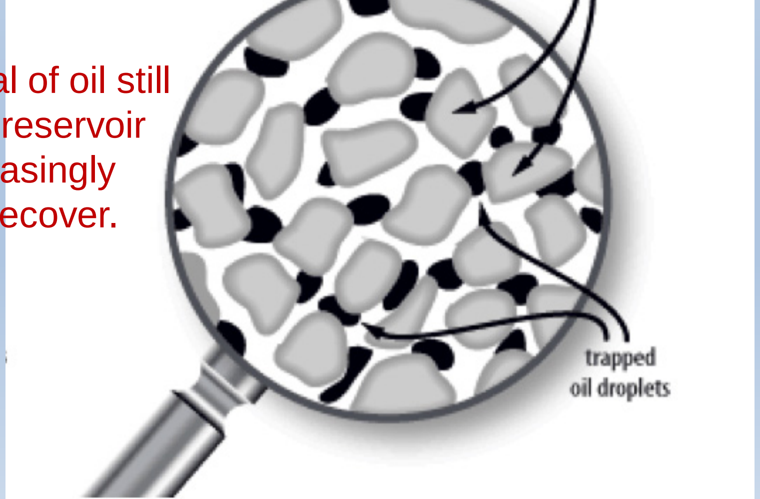
3. BEFORE DRILLING:

Microscopic view of oil and sand compacted under pressure in the oil reservoir.



4. AFTER PRIMARY PRODUCTION

A great deal of oil still remains in reservoir but is increasingly difficult to recover.

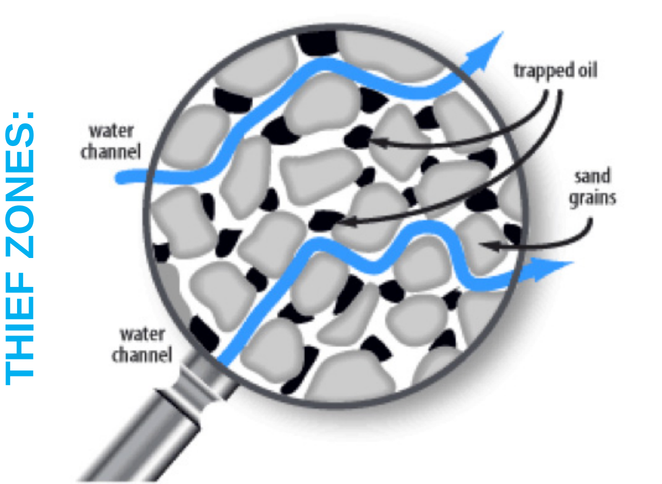


EOR & M-EOR: OPERATING MECHANISMS

Water-flood continues for some time, eventually water finds path of least resistance through the reservoir, and fissures (thief zones) open up in oil-bearing rock. The majority of injected water is then “short-circuited” directly to production well without pushing much oil out of rock. Oil production falls dramatically.

5. THIEF ZONES & FALLING PRODUCTION:

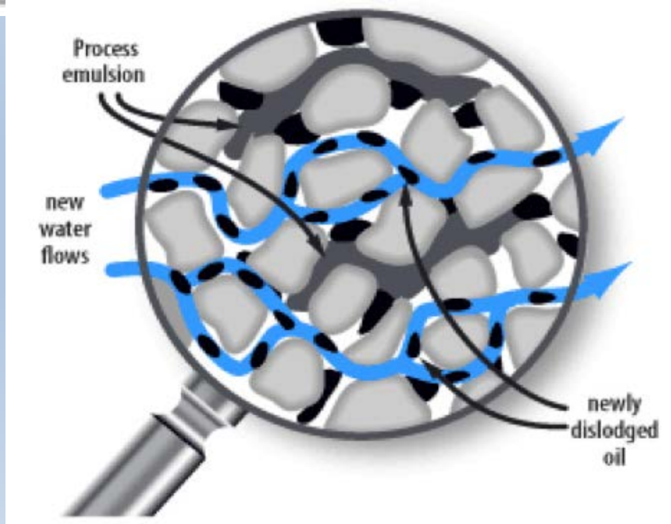
7. MICROSCOPIC THIEF ZONES:



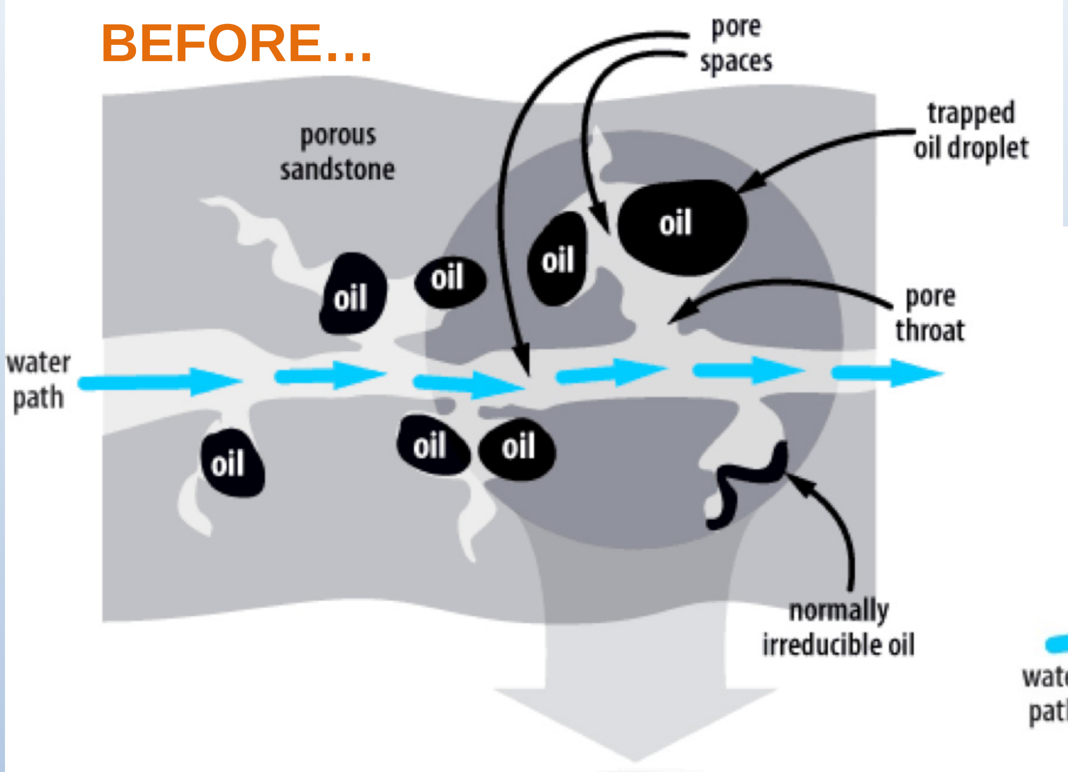
Microbial metabolites and nutrients feed the trillions of existing microbes in reservoir which multiply by 1000 times. These nutrients cause microbes to seek out and attach themselves to trapped oil droplets, dislodging them from rock and sand. Some of oil, water & microbes join to form a natural thick, viscous emulsion which blocks off the thief zones. Water is then forced to travel through other untapped areas of the reservoir, thereby increasing oil production.

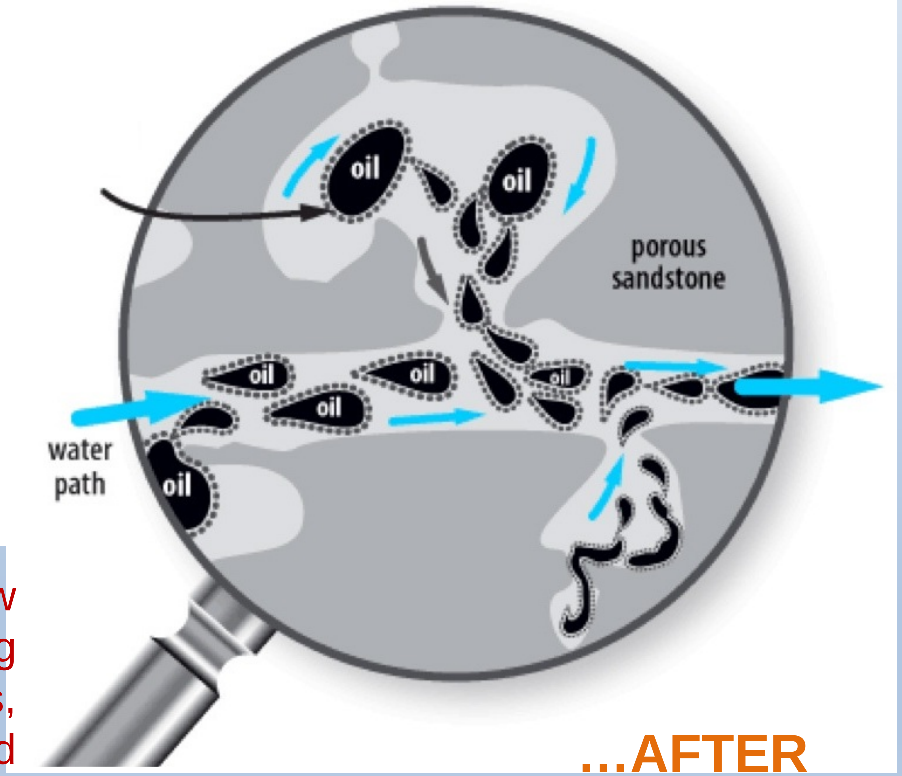
R

8. BLOCKING THIEF ZONES:



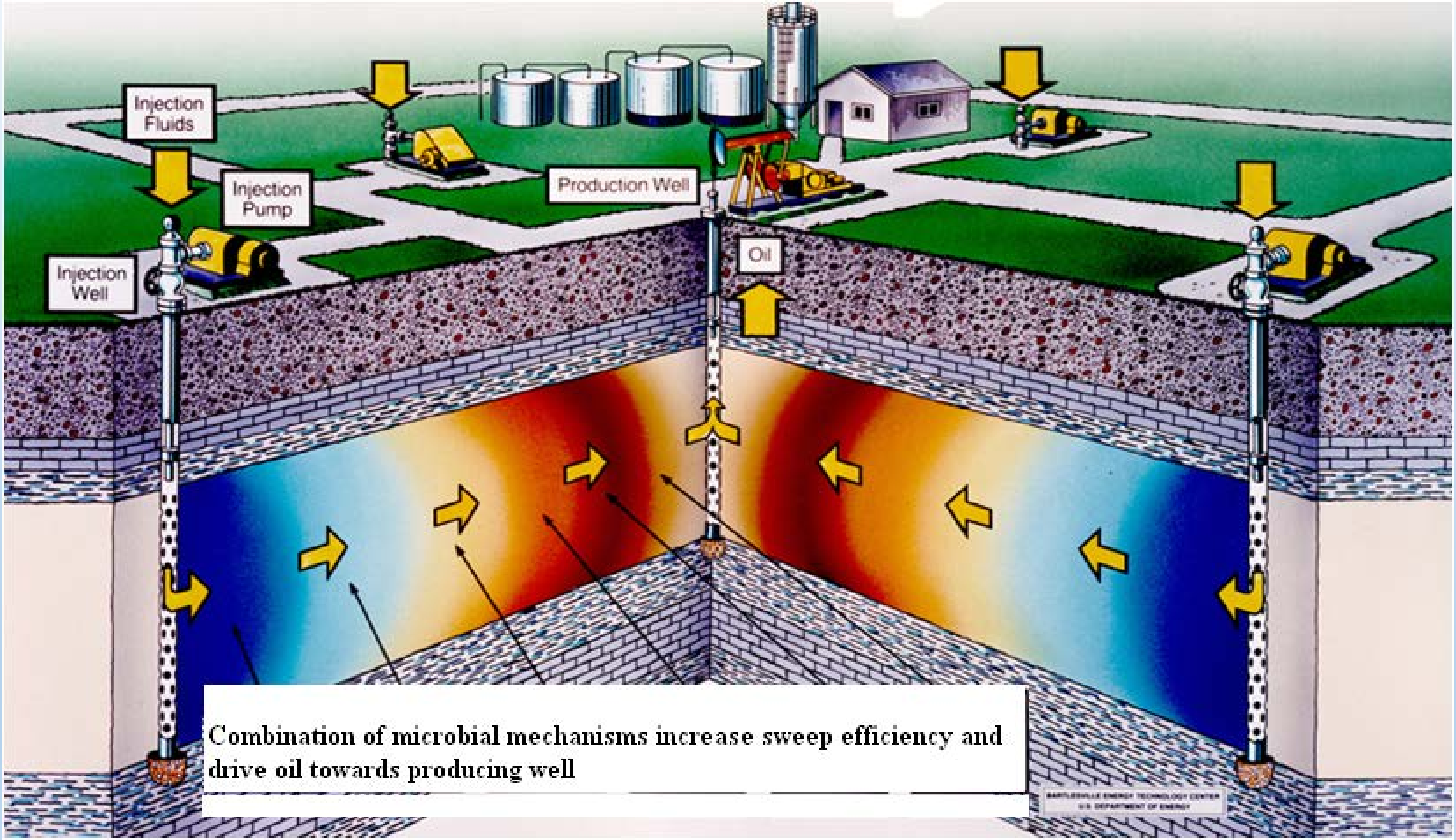
EOR & M-EOR: OPERATING MECHANISMS





Nutrients/surfactants/biopolymers create a new skin characteristic for the microbes, inducing them to seek out and surround oil droplets, causing the droplets to distort, break apart and dislodge from the microscopic pore spaces between the tiny sandstone and carbonate rock particles in the reservoir.

Schematic of *Ex-situ* MEOR Technology



OVERALL CONCEPT MAP OF *IN-SITU* MEOR

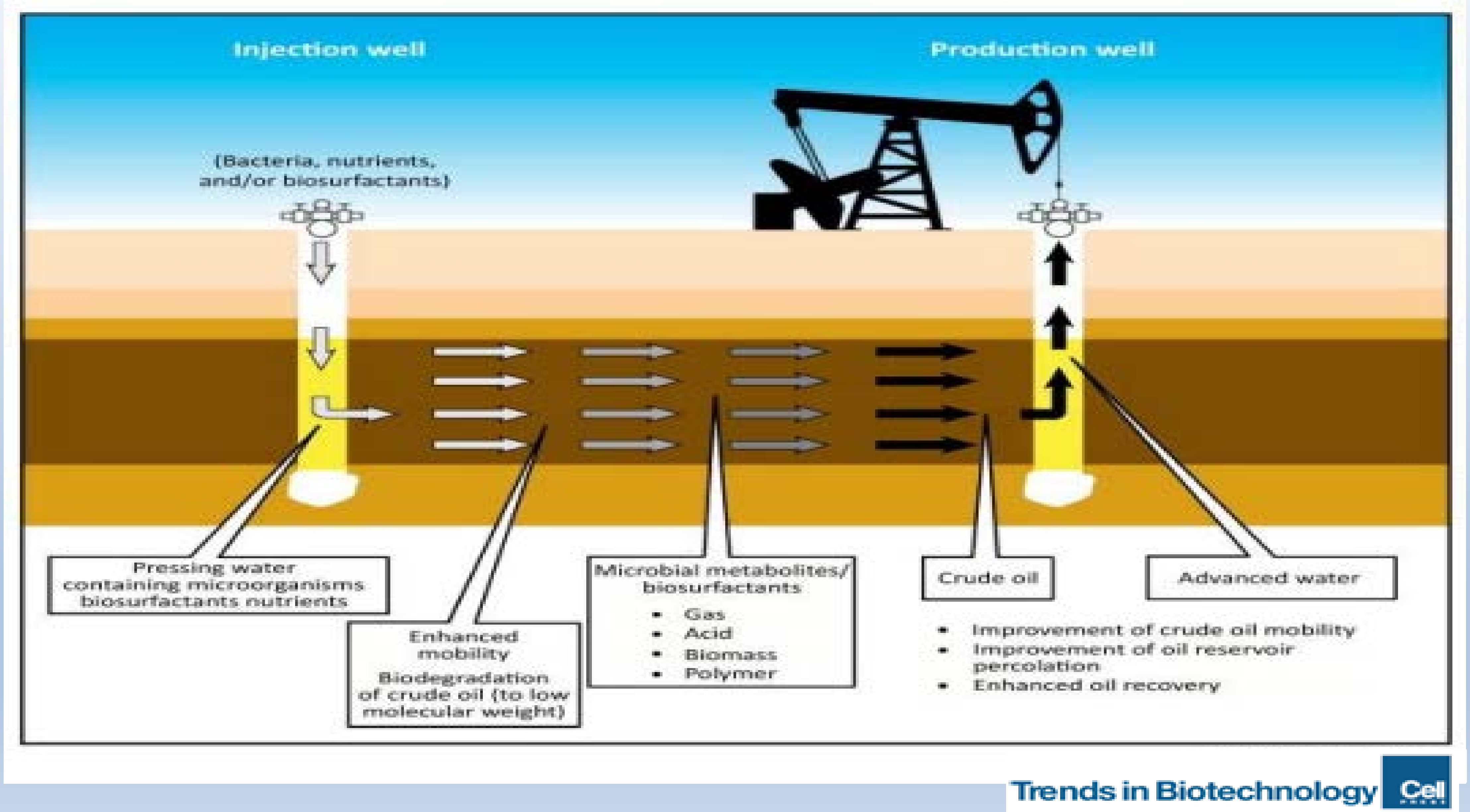


Table 1. Microbial products, their role in enhanced oil recovery, and some of the effects to solve production problems[a]

Microbial product	Role in enhanced oil recovery	Some of the effects
Gases (H_2, N_2, CH_4, CO_2)	• Reduce oil viscosity and improve flow characteristics • Displace immobile • Sweep oil in place	• Improved oil recovery by gases • Miscible CO_2 flooding
Acids (low molecular weight acids, primarily low molecular weight fatty acids)	• Improve effective permeability by dissolving carbonate precipitates from pores throat. Significant improvement of permeability and porosity • CO_2 produced from chemical reactions between acids and carbonate reduce oil viscosity and causes oil droplet to sweel	• Enhanced oil flooding
Solvents (alcohols and ketones that are typical cosurfactants)	• Dissolve in oil reduce viscosity • Dissolve and remove heavy, long chain hydrocarbons from pore throat (increase effective permeability) • Involved in stabilizing and lowering interf. tension that promotes emulsification • Reduce interfacial tension	• Emulsification promotion for increased miscibility
Biosurfactants	• Reduce interfacial tension between oil and rock/water surface which causes emulsification; improving pore scale displacement • Alter wettability	• Microbial surfactant • Flooding
Biopolymers	• Improve the viscosity of water in waterflooding and direct reservoir fluids to previously unswept areas of the reservoir • Improve the sweep efficiency of waterflood by plugging high permeability zones or water-invaded zones • Control of water mobility	• Microbial permeability modification (selective plugging)
Biomass (microbial cells)	• Physically displace oil by growing between oil and rock/water surface • Reversing wettability by microbial growth • Can plug high permeability zones • Selective partial degradation of whole crude oil • Act as selective and nonselective plugging agents in wetting, alteration of oil viscosity, oil power point, desulfuration	• Same biopolymers

Sen, 2008

Biopolymers & Biosurfactant that have potential applications as mobility control agents in MEOR

Bio surfactant	Microbial source
Surfactin Lichenysin	*Bacillus sp.*
Emulsan Alasan	*Acinetobacter sp.*
Rhamnolipid	*Pseudomonas sp.* *Bacillus sp.*
Viscosin Trehaloselipid	*Rhodococcus sp.*

Biopolymer	Microbial source
Xanthum gum	*Xanthomonas sp.*
Pullulan	*Aureobasidium sp.*
Levan	*Bacillus sp.*
Dextran	*Leuconostoc sp.*

Recent publications MEOR by our group

5-Year Impact Factor: 3.595

ELSEVIER

Journal of Biotechnology

journal homepage: www.elsevier.com/locate/jbiotec

Biosurfactant-biopolymer driven microbial enhanced oil recovery (MEOR) and its optimization by an ANN-GA hybrid technique

CrossMark

Gunaseelan Dhanarajan[a,1], Vivek Rangarajan[a,b,1], Chandrakanth Bandi[a], Abhivyakti Dixit[a], Susmita Das[c], Kranthikiran Ale[a], Ramkrishna Sen[a,*]

Cold Spring Harbor Laboratory

bioRxiv

THE PREPRINT SERVER FOR BIOLOGY

HOME | ABOUT

Search

New Results

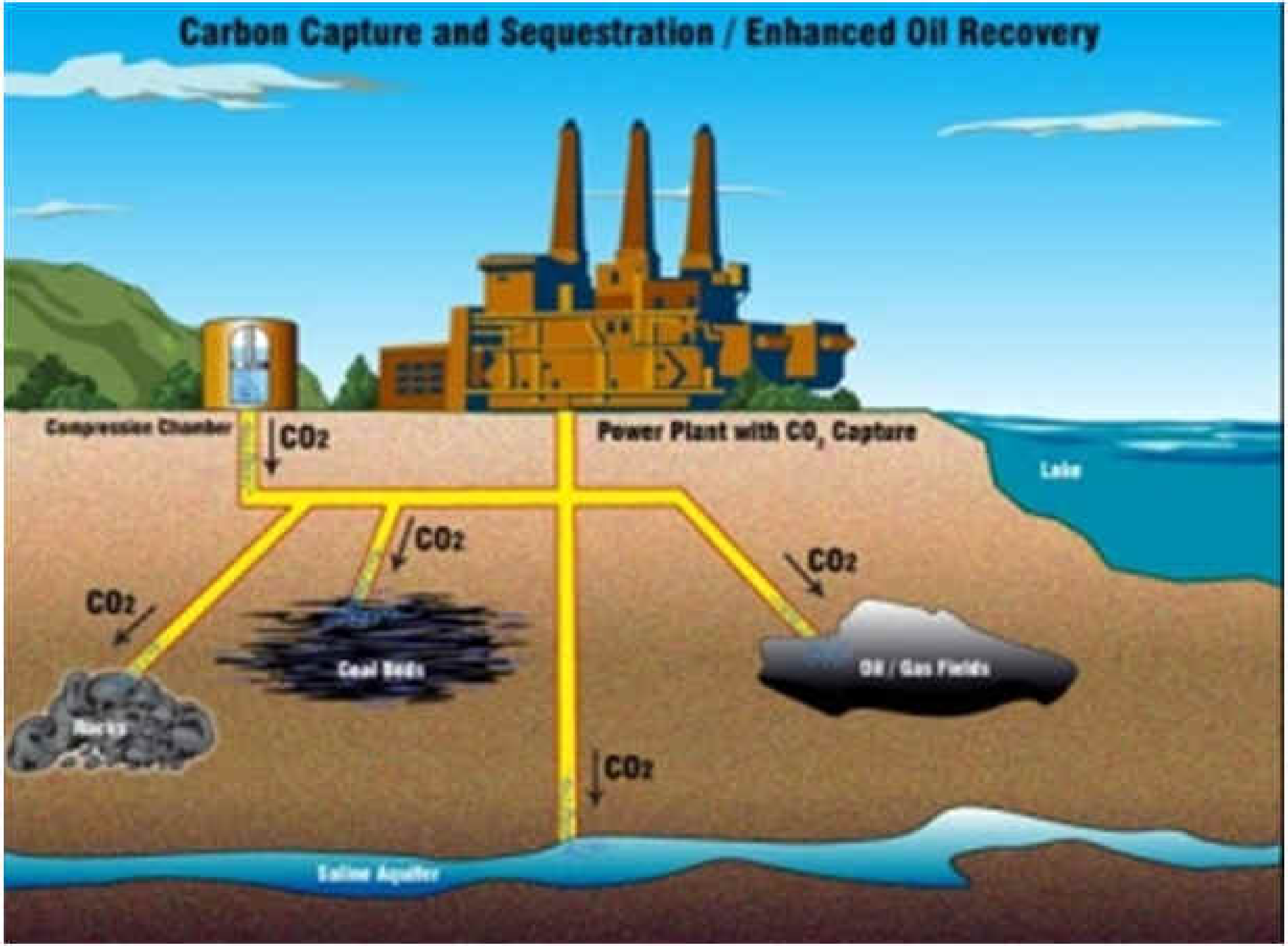
Comment on this paper

Performance evaluation of biosurfactant stabilized microbubbles in enhanced oil recovery

Gunaseelan Dhanarajan, Shaheen Perveen, Anirban Roy, Sirshendu De, Ramkrishna Sen

doi: https://doi.org/10.1101/504431

Simultaneous CO_2–Capture & MEOR:



Darcy's law is crucial to understanding many branches of geology, especially hydrogeology. Before we look at the law and what it can tell us, let's look at how it was developed. Darcy's law is named after Henry Darcy, a 19th century French engineer who developed an underground pressurized pipe system to deliver water around the city of Dijon. The system, which also provided water to the famous Dijon fountains, revolutionized city water and sewage systems. The system required no pumps and was driven purely by gravity. During the process of developing the new system, Darcy conducted a series of experiments where he tried to move water solely using gravity.

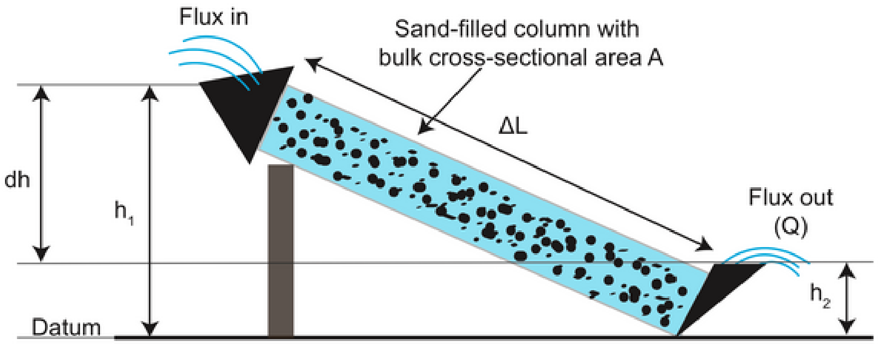


Figure 2.5.1: Model of Darcy's Experiment (MIB: need to correct drawing, ΔL should be L)

From the experiments, collected data on the length of the flume (L), the cross sectional area of the flume (A), the height difference ($h_1 - h_2$), and the flux of water coming out Q both with and without granular (filtering) material in the flume. He then plotted the flux measurement normalized by the area versus the ratio of the height difference to the length of the flume ($\frac{h_1-h_2}{l}$). What he found is that there is a linear relationship, and the slope depends on the granular material he used in the flume:

$$\frac{Q}{A} \propto \frac{h_1 - h_2}{L} \tag{2.5.1}$$

which can be rewritten as a derivative,

$$Q = -KA\frac{dh}{dx} \tag{2.5.2}$$

where K is the hydraulic conductivity and $\frac{dh}{dx}$ is the hydraulic gradient. Q, the total discharge rate, has units of $\frac{m^3}{s}$, the volume of water per time. The negative sign is due to the fact that the fluid flows down (negative) the hydraulic gradient from higher values to lower values.

MATHEMATICAL MODELLING OF EOR

The world's energy consumption has risen tremendously since 1930's for which fossil fuel such as oil has been used as a primary source of energy to meet the rising demand. As a result, Enhanced Oil Recovery (EOR) methods are used in the oil industry to increase the ultimate recovery of crude oil after primary and secondary productions. The residual oil is retained in the pore space due to viscous and capillary forces commonly influenced by interfacial tension, wettability and permeability. EOR is aimed to alter these parameters in beneficial ways [29–31, 63].

Mobility ratio and capillary number have been used in analysis of the expected oil production from the application of different EOR mechanisms. In [33] the mobility ratio is given by,

$$M = \frac{\lambda_D}{\lambda_d},$$

where λ_D and λ_d are mobilities of the displacing and displaced fluids respectively. The case $M < 1$ tells us the mobility of the displacing fluid is smaller than that of the displaced fluid which implies that the displaced fluid can be mobilized. On the other hand, the Capillary number N_c, is defined as (see [34])

$$N_c = \frac{\mu q}{\sigma},$$

where q is Darcy velocity, μ is the viscosity of displacing fluid and σ is fluid-fluid interfacial tension. A low interfacial tension σ, results in weak capillary forces which is of great importance for displacement and gives high N_c. In other word, high N_c lowers the residual oil saturation.

Though the Monod expression is empirical regarding with microbial growth, it has been used widely to describe the relation between the bacterial growth rate and substrate [4, 16, 17, 21–23, 48]. And thus, the Monod type growth rate for one limiting substrate is given as

$$G_b = G_{\max}\frac{C_s}{K_s + C_s}, \tag{3.2.6}$$

where K_s is half-saturation constant, $G_{\max}$ maximum growth rate, and C_s is the limiting substrate concentration in the water phase. In practice, bacterial decay occurs, but we assume, that the growth rate covers the net growth rate.

If we further assume the growth inhibition does not occur, the corresponding reaction/source term R_b is expressed as

$$R_b = Y_{sb} G_b C_b, \tag{3.2.7}$$

where Y_{sb} is the yield of bacteria on substrate.

It is convenient to assume that metabolite/bio-surfactant production occurs in both the planktonic (unattached and sessile (attached) phases of bacteria. An empirical equation is used to calculate metabolite production rate as growth rate of bacteria. The source term for metabolite equation can be stated as

$$R_m = Y_{sm} C_b G_b. \tag{3.2.8}$$

As can be seen above microbial growth and metabolite production are granted by substrates consumption which is given by

$$R_s = -R_b - R_m. \tag{3.2.9}$$

In other words, equation (3.2.9) describes the reaction term after the injected substrate contributed to the growth of bacteria and production of bio-surfactant.

Advantages of MEOR:

1. Producing petroleum using its own products can never be feasible.

2. In-situ MEOR involves injection of nutrients and microbial cell factories/consortia that are inexpensive resources, easy to obtain and handle in the oil field and hence, offers an economically attractive option for depleted oil reservoirs and a suitable and viable EOR alternative, before abandoning the marginal oil wells.

3. Input of energy to produce the MEOR agents *in-situ*.

4. Compared to other EOR processes MEOR technologies require less modification of the existing field characteristics and are more cost-effective, easy to install and implement.

5. Since the injected MEOR agents are not petrochemicals, their costs are not dependent on the global crude oil price.

6. MEOR processes are particularly suited for carbonate oil reservoirs, which are not amenable to some conventional EOR technologies.

7. MEOR products are all biodegradable and will not be accumulated in the environment, therefore are environmentally compatible.

HENCE, MEOR IS A BIOTECHNO-ECONO METHOD FOR ECO-FRIENDLY RECOVERY OF PETROLEUM….


Thank you