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CHEMICAL EOR – THE PAST, DOES IT HAVE A FUTURE?

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THE PAST :
Limited Commercial Success

FUTURE : Very Bright

- Past experience
- High oil prices
- Scaled models

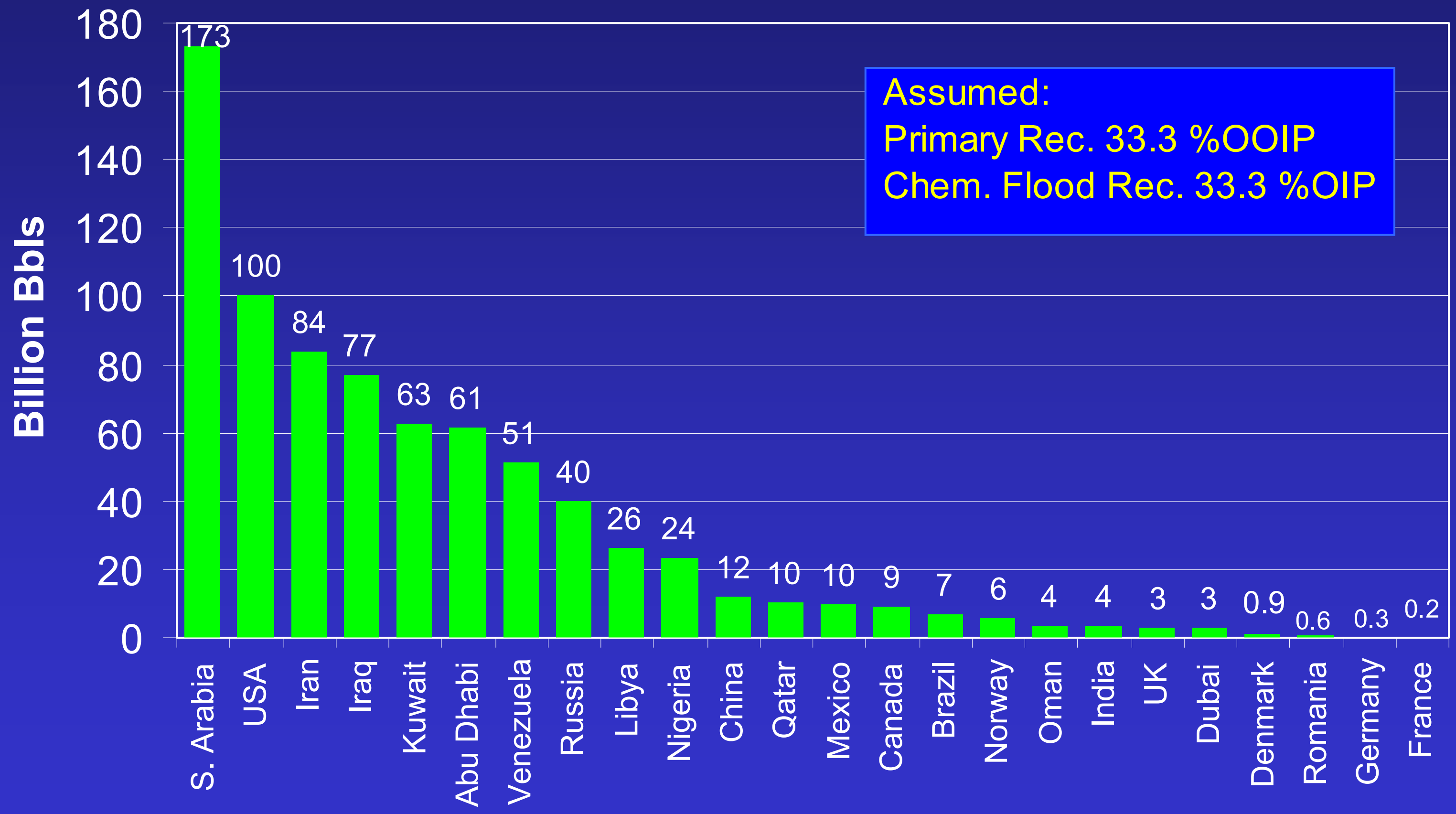
OBJECTIVES

- Why chemical EOR methods have not been successful?
- Process limitations
- Current status of chemical floods
- Recent changes that make such methods attractive

CHEMICAL EOR HOLDS A BRIGHT FUTURE

- Conventional oil RF <33%, worldwide
  - "Unrecoverable" oil = 2×10^{12} bbls
  - Much of it is recoverable by chemical methods
- Chemical methods are attractive:
  - Burgeoning energy demand and high oil prices, most likely for the long-term
  - Diminishing reserves
  - Advancements in technologies
  - Better understanding of failed projects

CHEMICAL EOR TARGET IN SELECTED COUNTRIES



CHEMICAL METHODS

- Chemical EOR methods utilize:
  - Polymers
  - Surfactants
  - Alkaline agents
  - Combinations of such chemicals
    - ASP (Alkali-Surfactant-Polymer) flooding
    - MP (Micellar-Polymer) flooding

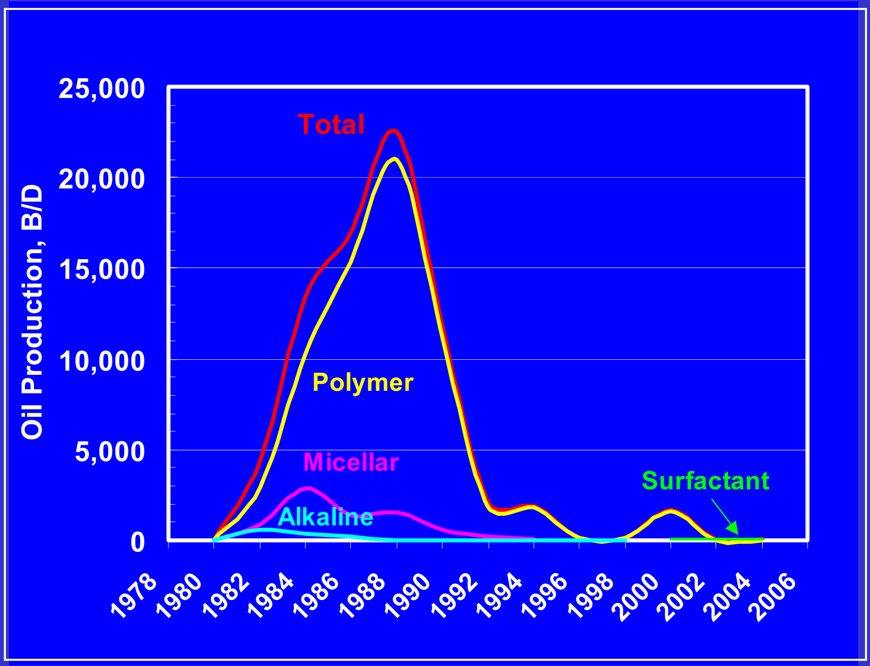
CLASSIFICATION

CHEMICAL METHODS

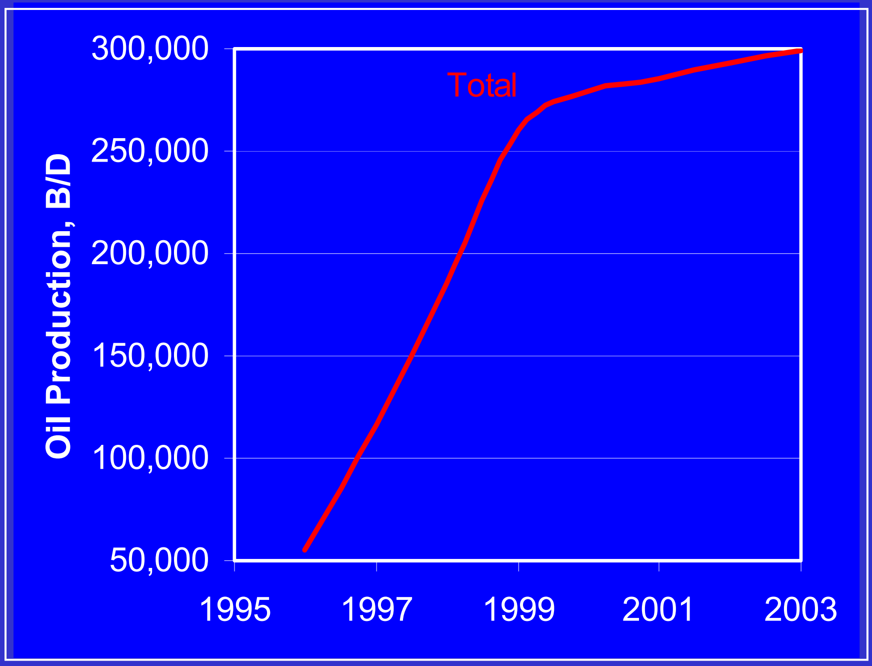
- Alkali
- Polymer
- Surfactant
- Emulsion
- Micellar
- ASP

CHEMICAL FLOODS HISTORY

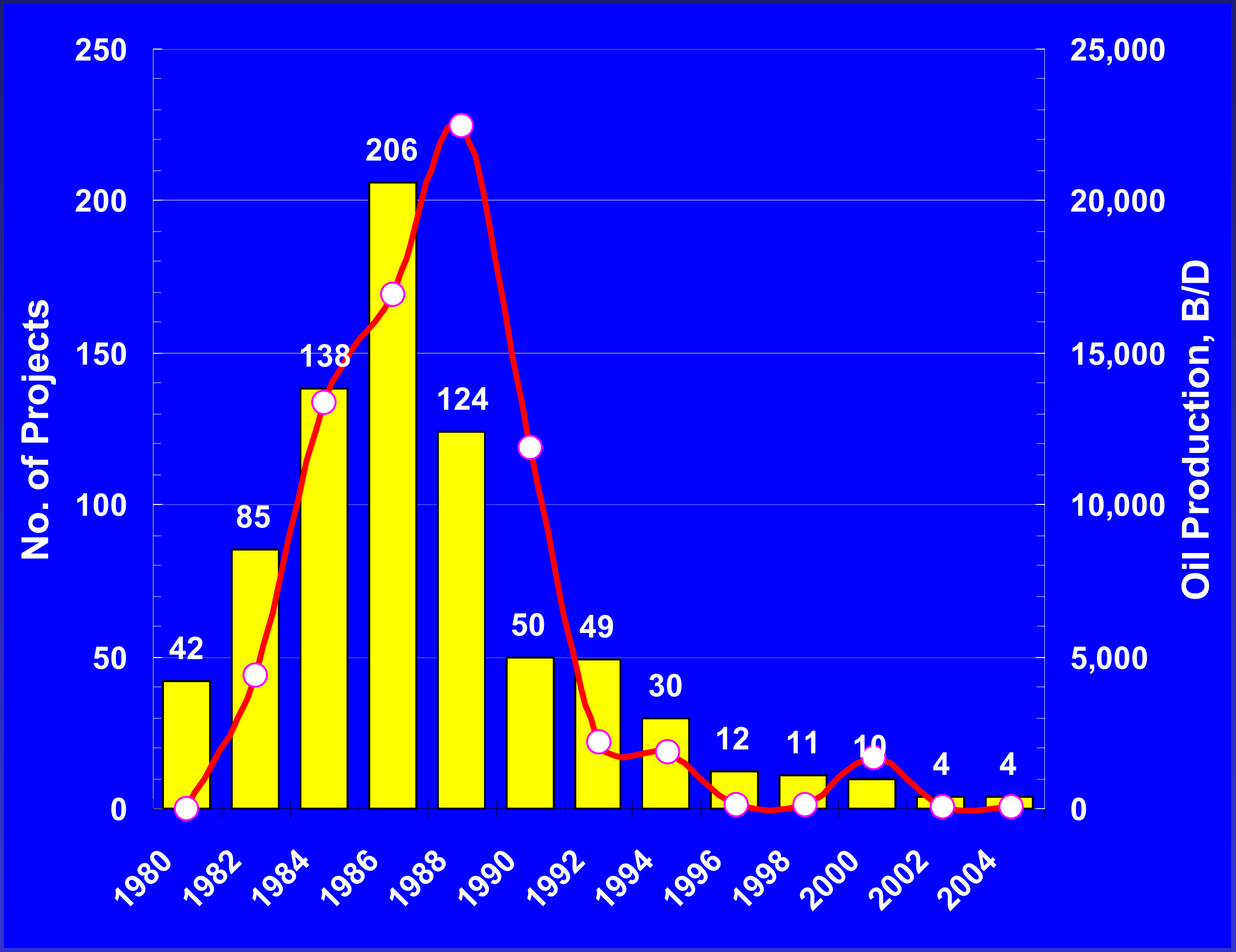
USA



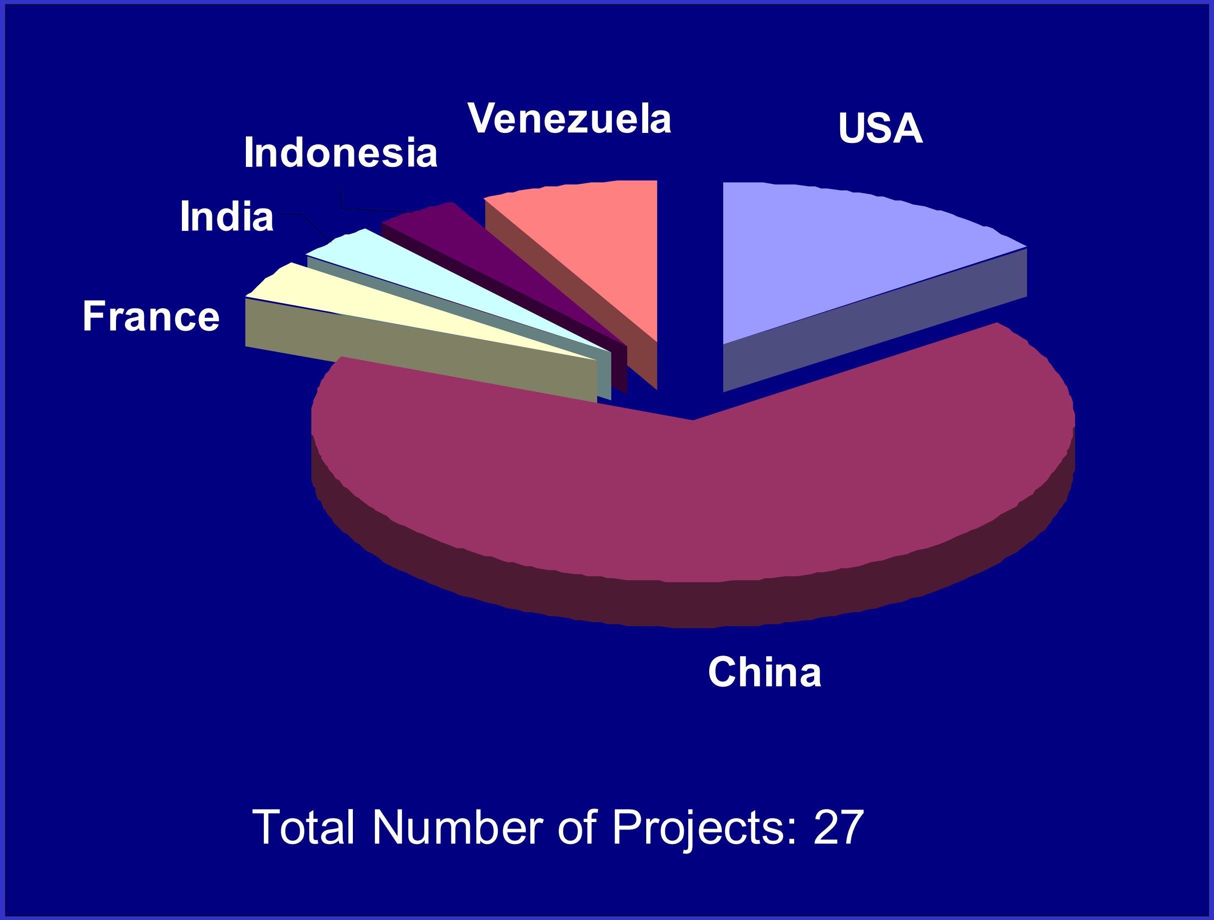
CHINA



CHEMICAL FLOODS PROJECTS AND PRODCTION IN THE USA

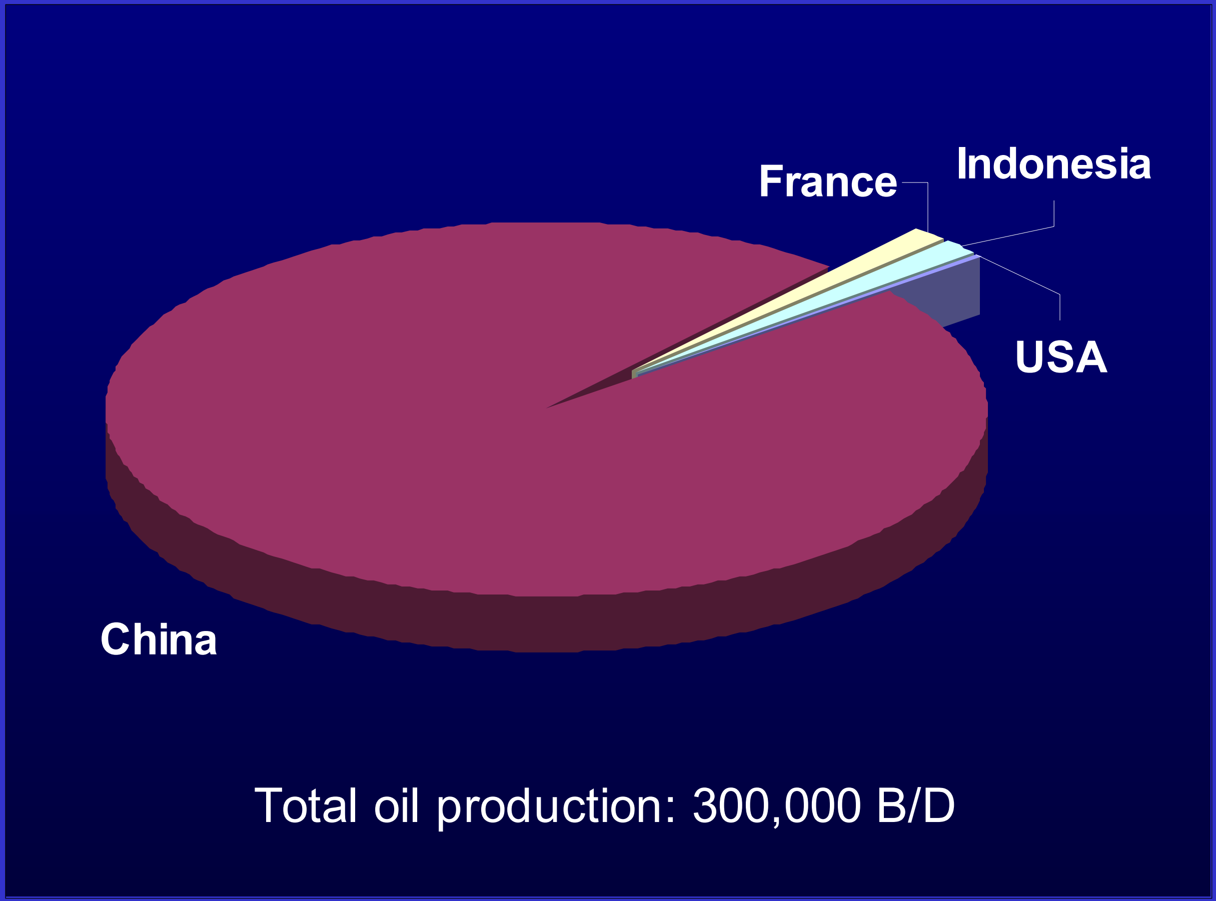


Chemical Floods - CURRENT STATUS WORLDWIDE



OGJ April 12, 2004

Chemical Floods -
PRODUCTION WORLDWIDE



OGJ April 12, 2004

OBJECTIVES OF CHEMICAL FLOODING

- Increase the Capillary Number N_c to mobilize residual oil
- Decrease the Mobility Ratio M for better sweep
- Emulsification of oil to facilitate production

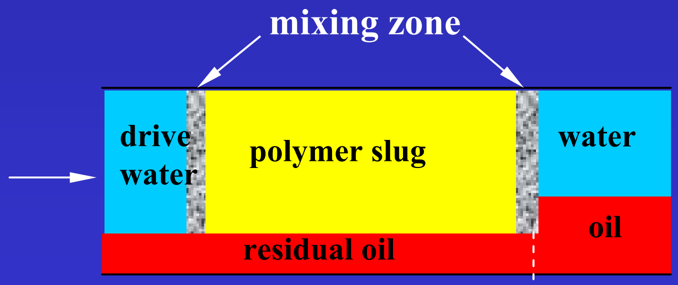
Chemical Flooding -

GENERAL LIMITATIONS

- Cost of chemicals
- Excessive chemical loss: adsorption, reactions with clay and brines, dilution
- Gravity segregation
- Lack of control in large well spacing
- Geology is unforgiving!
- Great variation in the process mechanism, both areal and cross-sectional

POLYMER FLOODING

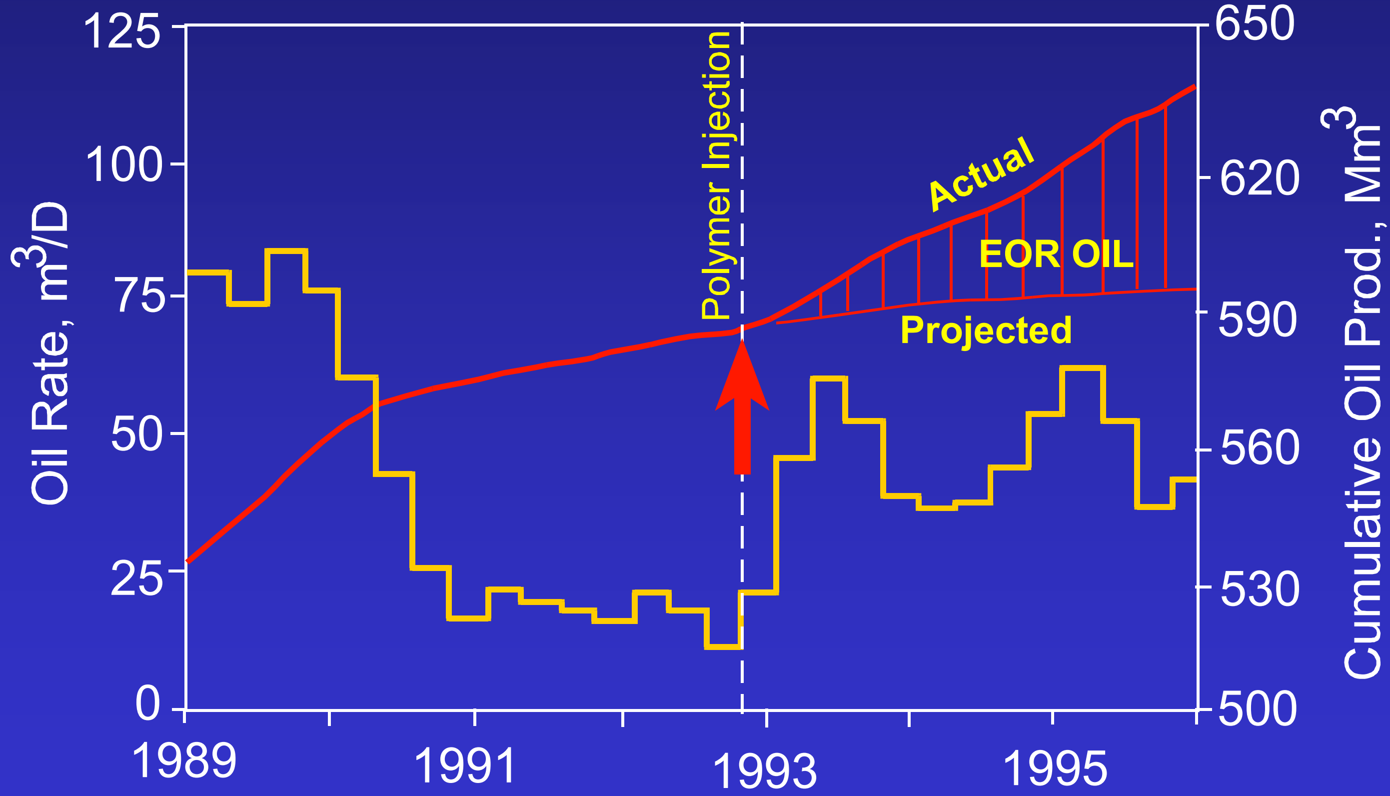
- Loss to rock by adsorption, entrapment, salt reactions
- Loss of injectivity
- Lack of control of in situ advance
- High velocity shear (near wellbore), ageing, cross-linking, formation plugging
- Often applied late in waterflood, making it largely ineffective



Polymer Flood

Polymer Flood - FIELD PERFORMANCE

Sanand Field, India

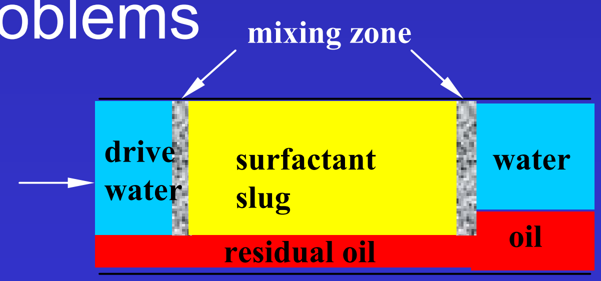


Polymer Flood – FIELD PROJECTS

Project	Flood Type	Formation	Polymer	Rec., %OIP
1 Taber Manville South	Secondary	Sandstone	PAA	2
2 Pembina	"	"	"	0
3 Wilmington	"	"	"	0
4 East Colinga	"	"	Biopolymer	0
5 Skull Creek South	"	"	PAA	8
6 Skull Creek Newcastle	"	"	"	10
7 Oerrel	"	"	"	23
8 Hankensbuettel	"	"	"	13
9 Owasco	"	"	"	7
10 Vernon	"	"	"	30
11 Northeast Hallsville	"	Carbonate	"	13
12 Hamm	"	Sandstone	"	9
13 Sage Spring Cr. Unit A	"	"	"	1.2
14 West Semlek	"	"	"	5
15 Stewart Ranch	"	"	"	8
16 Kummerfeld	"	"	"	6
17 Huntington Beach	"	"	"	4
18 North Stanley	Tertiary	"	"	1.1
19 Eliasville Caddo	Tertiary	Carbonate	"	1.8
20 North Burbank	Tertiary	Carbonate	"	2.5

SURFACTANT FLOODING

- Variations
  - Surfactant-Polymer Flood (SP)
  - Low Tension Polymer Flood (LTPF)
- Adsorption on rock surface
- Slug dissipation due to dispersion
- Slug dilution by water
- Formation of emulsions
  - Treatment and disposal problems



Surfactant Flood

Surfactant flood -

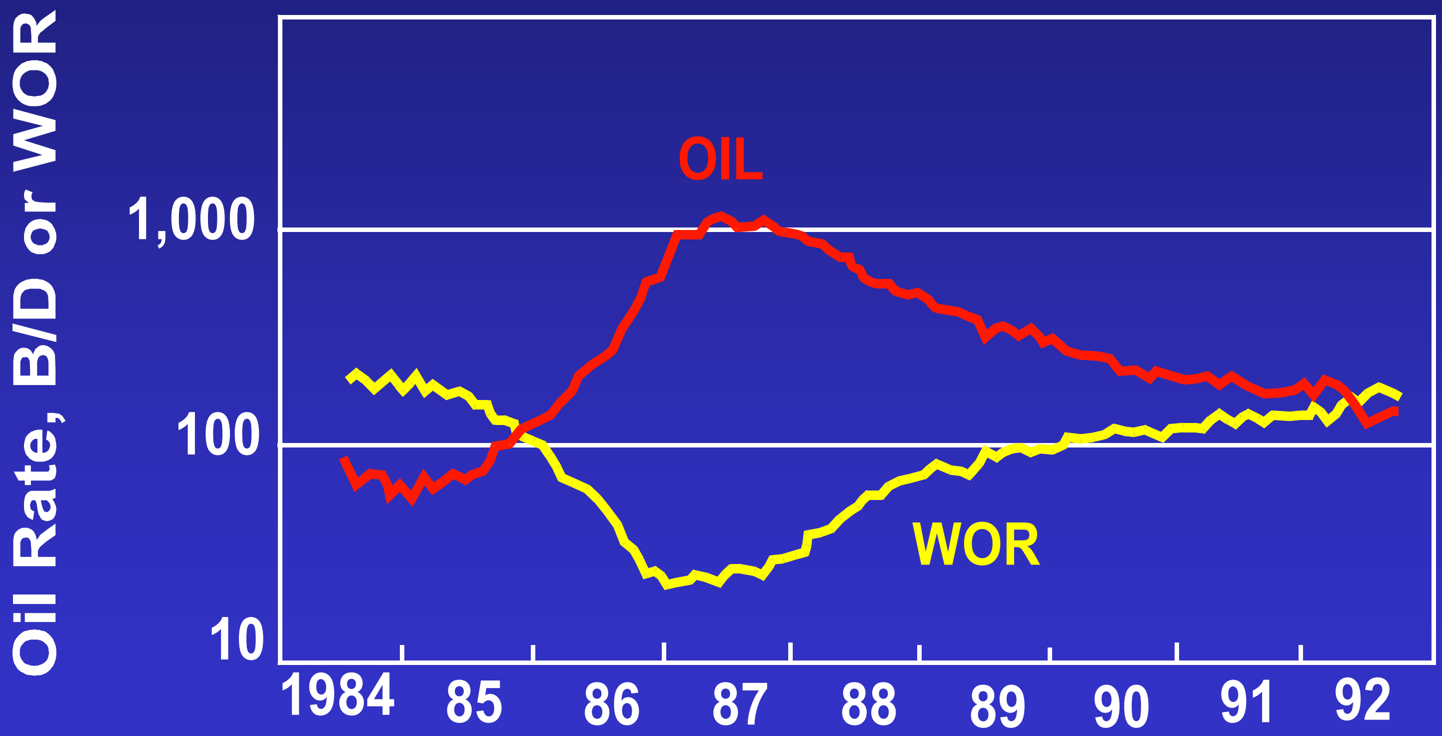
FIELD PROJECTS

	Project	Pattern Size	Chemical Slugs Type	PV	T. Rec. % OIP	Comments
1	Benton ILL	1 acre, 5 - spot	preflush, surf. formulation polymer buffer	1.4 4.2	10	Injection problems, Emulsion production, Poor sweep efficiency
2	Salem Unit ILL	5 acre 5 - spot	preflush, surf. formulation polymer buffer (Biopolymer)	0.3 0.3	14	Surf. Precipitation, High surfactant loss, Schedule change due to delay in surf. Supply.
3	Big Muddy WY	10 - acre 5 - spot x 9	preflush, surf. formulation polymer buffer	0.1 0.18	10	Faults and fractures, Poor fluid confinement, Pressure parting, Poor sweep efficiency Emulsion production, Corrosion
4	Glenn Pool OK	92 acres	preflush, surf. formulation polymer buffer	0.1 0.7	32	Lack of mobility control, Low oil prices made expansion uneconomic.

Surfactant flood -

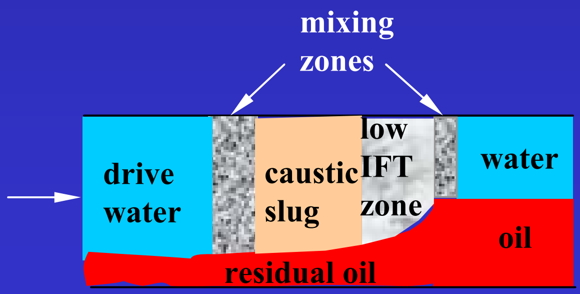
FIELD PERFORMANCE

Glenn Pool Field, OK



ALKALINE FLOODING

- Process depends on mixing of alkali and oil
  - Oil must have acid components
- Emulsification of oil, drop entrainment and entrapment occur
  - Effect on displacement and sweep efficiencies?
- Polymer slugs used in some cases
  – Polymer alkali reactions must be accounted for
- Complex process to design



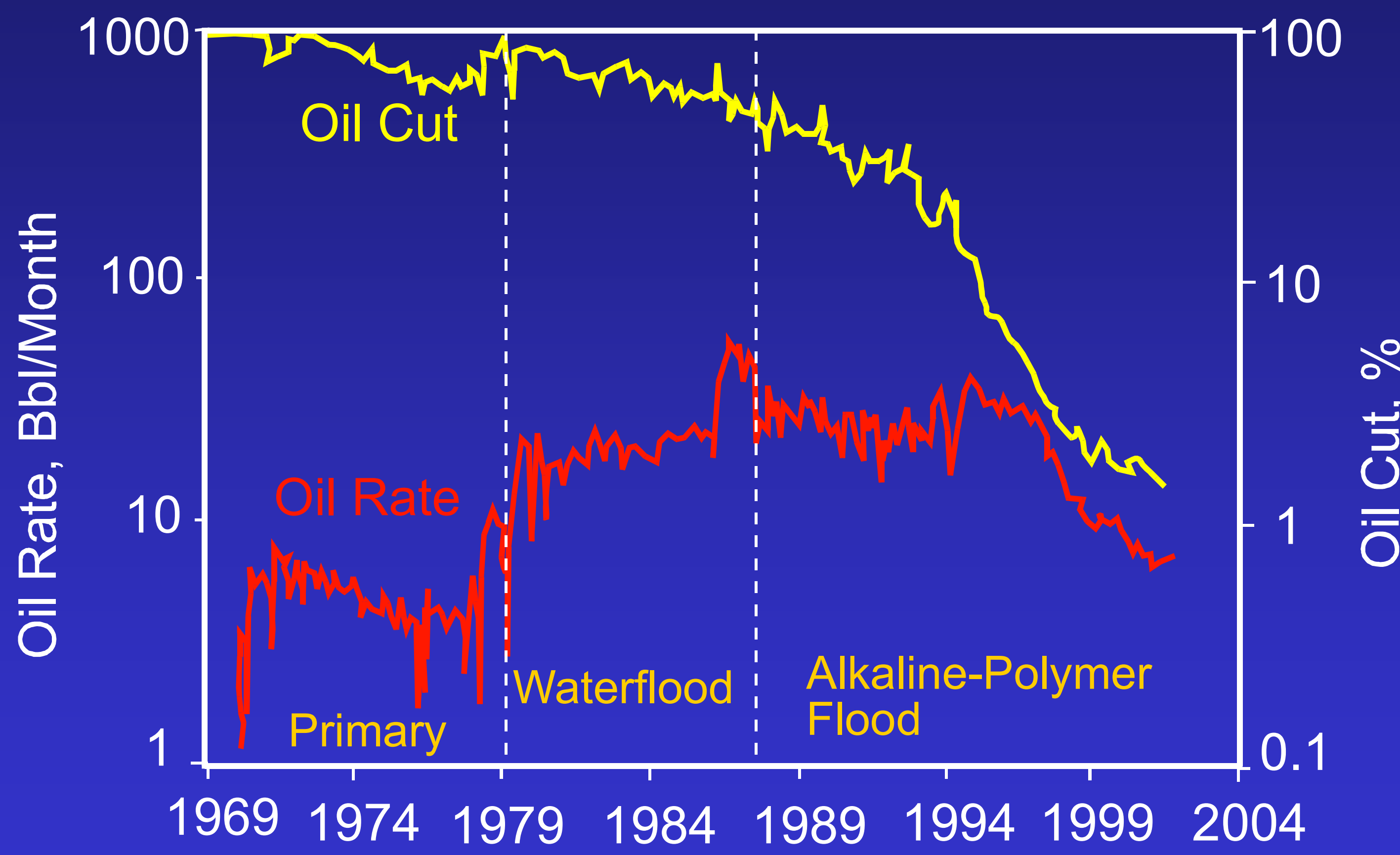
Alkaline flooding -

FIELD PERFORMANCE

	Field	Slug Size	Conc.	Oil Satn.	Consum.	Oil Rec.
		% PV	wt%	%PV	mg/g rock	%OIP
1	Whittier	8	0.2	51	2.4-11.2	4
2	Singleton	8	2.0	40	-	5
3	N. Ward Estes	15	4.9	64	17.2	8
4	L. A. Basin	5	0.4	30	-	3
5	Orcutt Hill	2	0.42	50	0.5	2
6	Van	12	0.14	25-35	0.6-1.2	3
7	Kern River	48	0.15	52	1.3	none
8	Harrisburg	9	2.0	30-40	-	6
9	Brea-Olinda	1.2	0.12	50-60	-	2

ALKALINE-POLYMER FLOOD

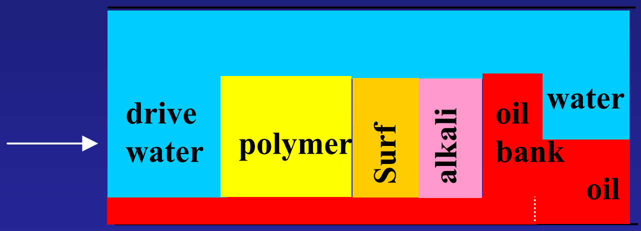
David Field, Alberta



ASP: ALKALI-SURFACTANT-POLYMER FLOODING

- Several variations:
  - ASP
  - SAP
  - PAS
  - Sloppy Slug

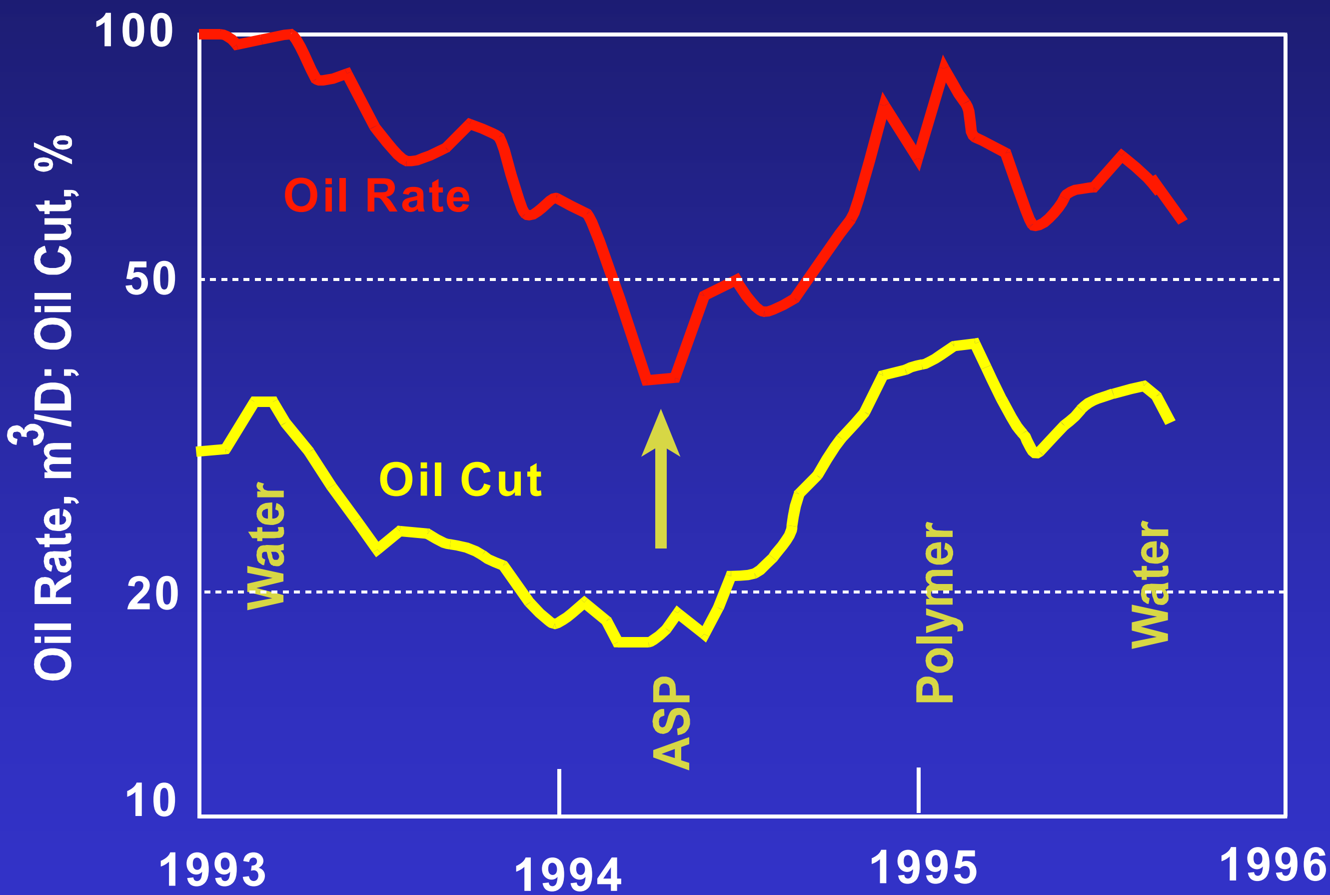
Injected as premixed slugs or in sequence



ASP Flood

- Field tests have been encouraging
- Successful in banking and producing residual oil
- Mechanisms not fully understood

ASP PILOT – Daqing, China



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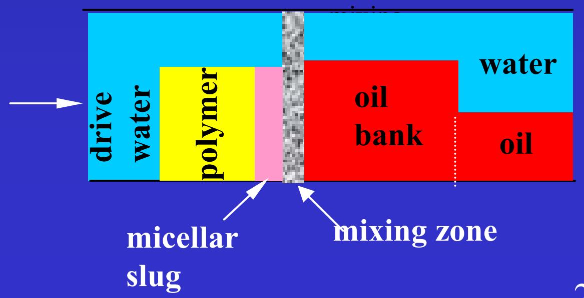
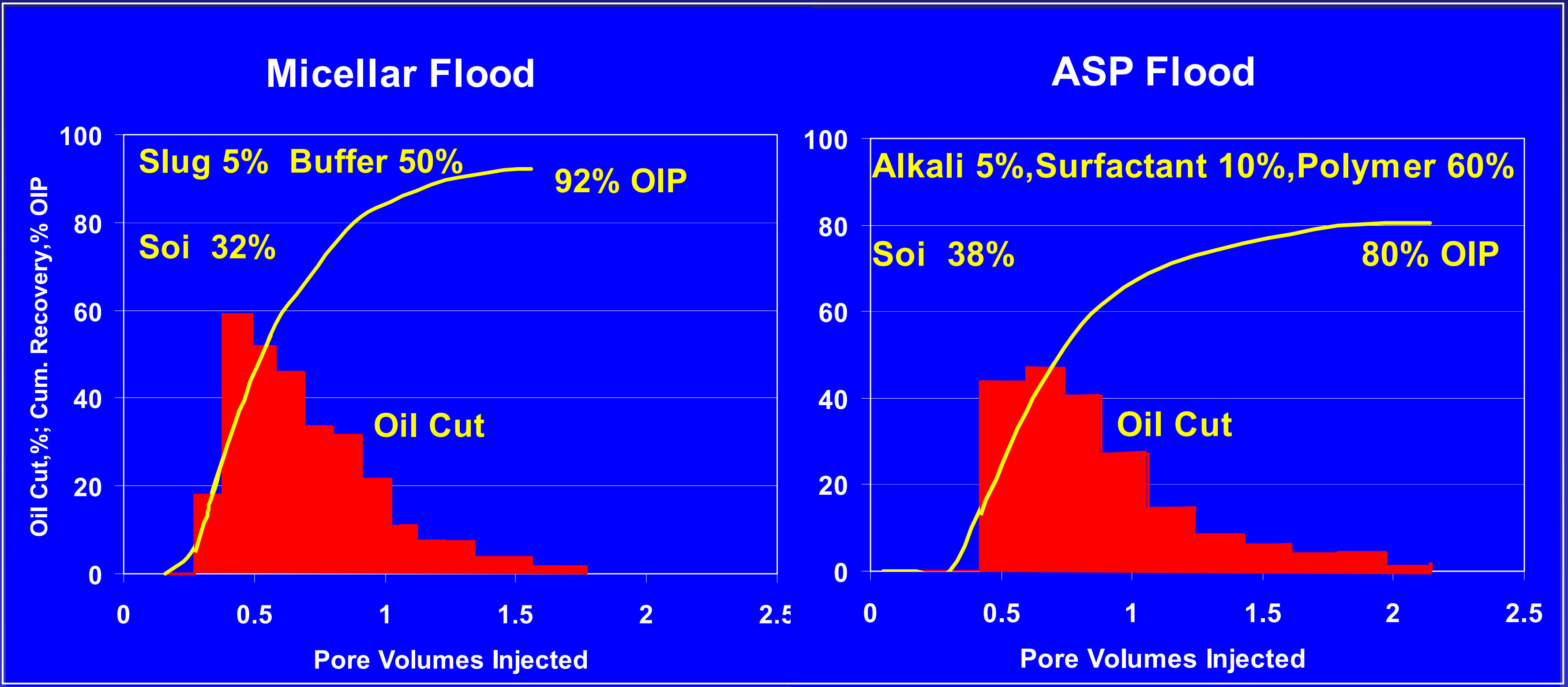
MICELLAR FLOODING

- Utilizes microemulsion and polymer buffer slugs
- Miscible-type displacement
- Successful in banking and producing residual oil
- Process Limitations:
  - Chemical slugs are costly
  - Small well spacing required
  - High salinity, temperature and clay
  - Considerable delay in response
  - Emulsion production

Micellar Flood



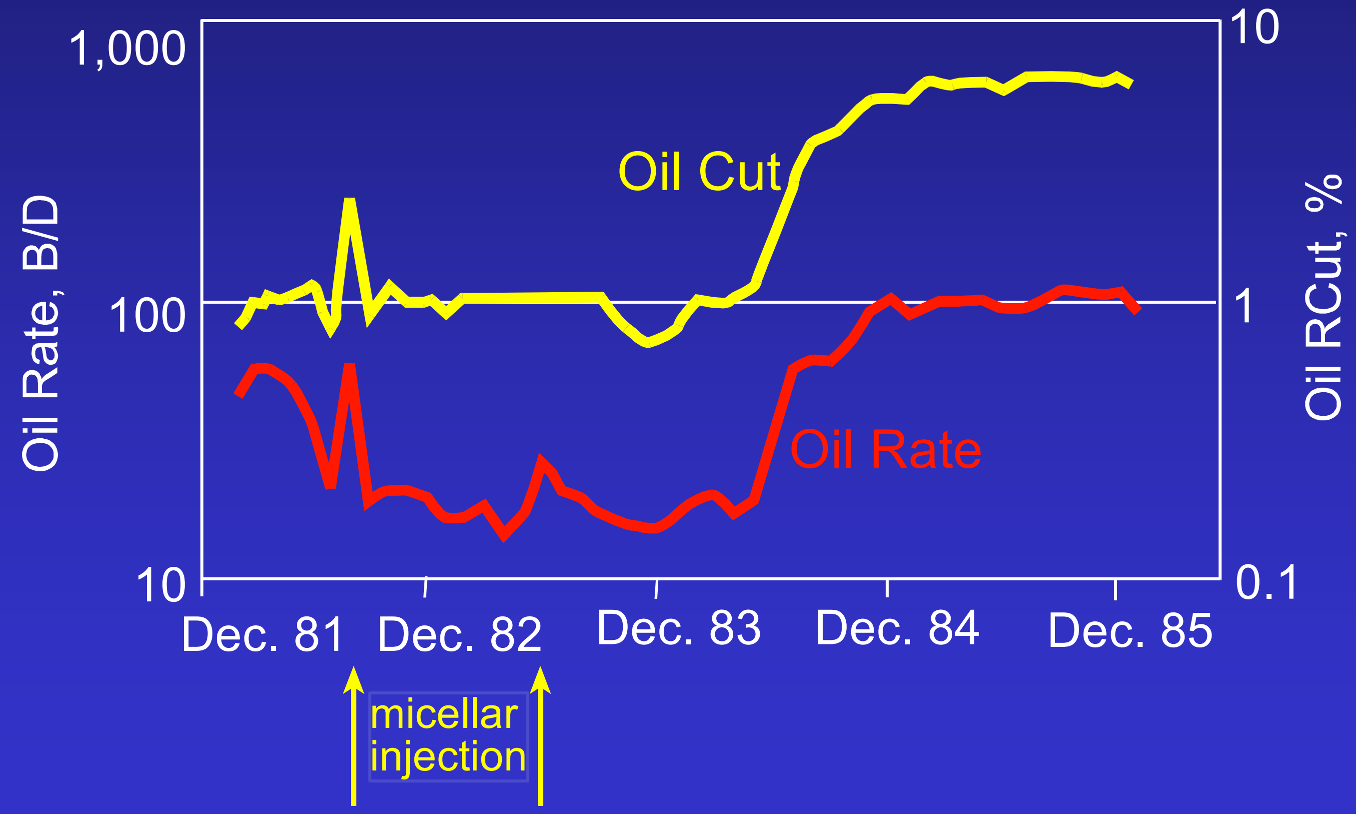
ASP vs. MICELLAR FLOOD -
Lab Results – Mitsue Oil Core Floods



Earlier oil breakthrough and quicker recovery in micellar flood

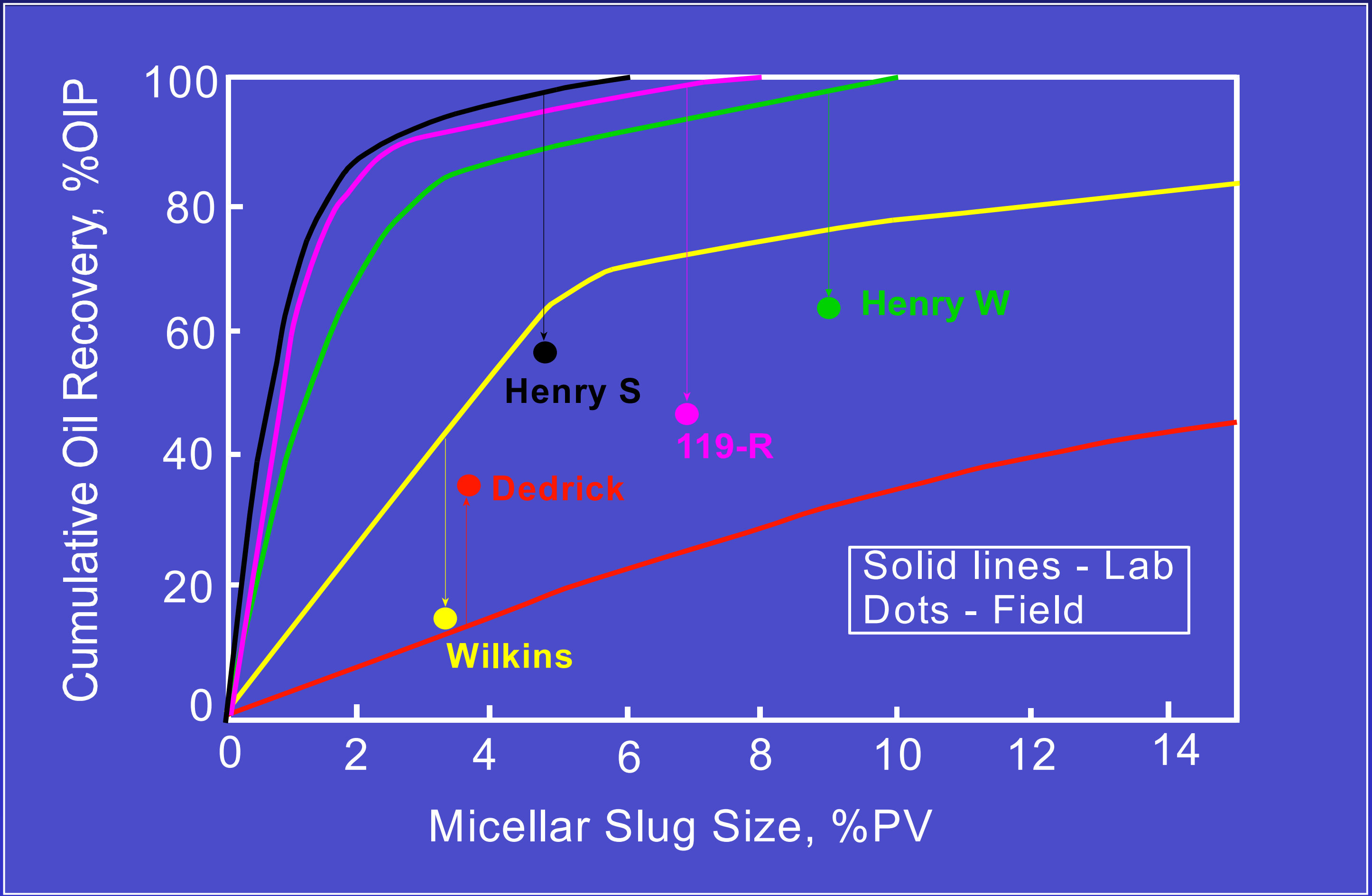
Micellar flood –
TYPICAL PERFORMANCE

Bradford Special Project No. 8



Micellar flood –

PROCESS EFFICIENCY



ASP AND MP FIELD PROJECTS

ASP Floods	Started	Appln.	Acre	Rec., %OIP
David, Alberta	1986	Tertiary	252	*21
West Kiehl, Wyoming	1987	"	106	34.4
Gudong, China	1992	"	766	29.4
Cambridge, Wyoming	1993	"	72	*26.8
Daqing, China	1994	"	8.4	23.9
Karamay, China	1996	"	766	*24
Viraj, India	2002	"	68	*24
Micellar Floods				
Dedrick (IL)	1962	Secondary	2.5	*49.7
Robinson, 119-R (IL)	1968	Tertiary	40	39
Benton (IL) Shell	1972	"	160	29
Robinson, 219-R (IL)	1974	"	113	27
North Burbank (OK)	1976	"	90	11
Robinson, M1 (IL)	1977	"	407	50
Bradford (PA)	1980	"	47	50
Salem Unit (IL)	1981	"	200	47
Louden (IL)	1977	"	40	27
Louden (IL)	1980	"	80	33
Chateaurenard, (France)	1983	"	2.5	67

* %OOIP

OTHER METHODS

- Emulsion flooding
- Micellar-Alkaline-Polymer flood (MAP)
- ASP-Foam process
- Surfactant huff n'puff
- Surfactant with thermal processes

REASONS FOR FAILURE

- Low oil prices in the past
- Insufficient description of reservoir geology
  - Permeability heterogeneities
  - Excessive clay content
  - High water saturation
  - Bottom water or gas cap
  - Fractures
- Inadequate understanding of process mechanisms
- Unavailability of chemicals in large quantities
- Heavy reliance on unscaled lab experiments

SCALE-UP METHODS

- Require:
  - Knowledge of process variables *or* complete mathematical description
  - Derivation of scaling groups
  - Model experiments
  - Scale-up of model results to field
- Greater confidence to extend lab results to field

SCALING GROUPS

- Micellar Flood:

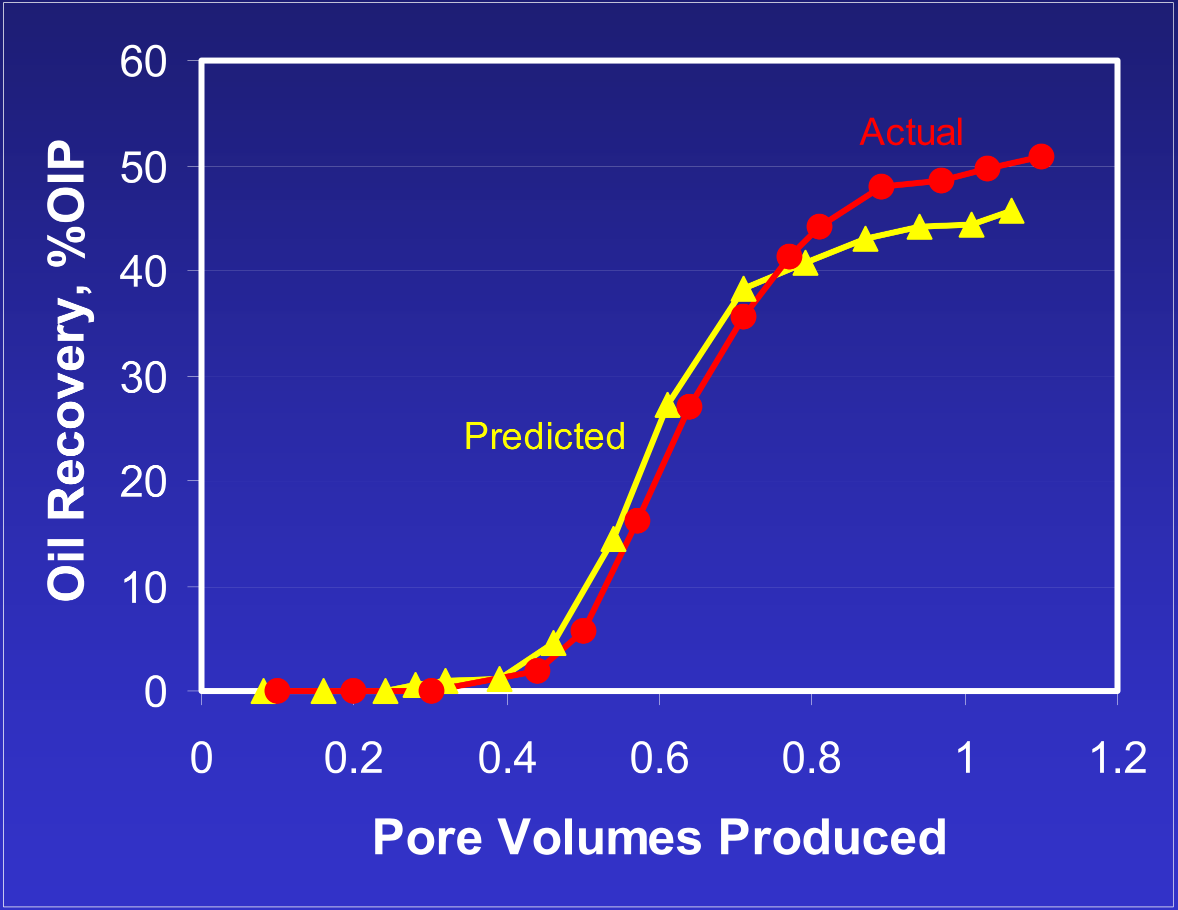
$$\left[\frac{L}{d}\right]\left[\frac{\Delta p}{\rho_o gh}\right]\left[\frac{P_{c_{LE_{\max}}}}{\rho_o gh}\right]\left[\frac{P_{c_{LE_{\max}}}}{P_{c_{EA_{\max}}}}\right]\left[\frac{k_{rw_{\max}}\mu_o}{k_{ro_{\max}}\mu_w}\right]\left[\frac{k_{rE_{\max}}\mu_w}{k_{rw_{\max}}\mu_E}\right]\left[\frac{q_A^*}{q_L^*}\right]\left[\frac{q_E^*}{q_L^*}\right]$$

$$\left[\frac{\phi S_{oi}\mu_o L^2}{kk_{ro_{\max}}\Delta pt}\right]\left[\frac{q_L^*\mu_o L^2}{kk_{ro_{\max}}\Delta p}\right]\left[\frac{\phi S_{oi}K_L\mu_o}{kk_{ro_{\max}}\Delta p}\right]\left[\frac{K_L}{K_T}\right]\left[\frac{C_s}{S_{oi}\rho_o C_{L,s}}\right]\left[\frac{C_s}{C_p}\right]$$

- Additional Groups:
  - Slug Size, Flood Rate, Mixing Coefficient, Oil Recovery

$$(PV)_{S_p}=\left(\frac{S_{oi_p}}{S_{oi_M}}\right)(PV)_{s_M} \qquad v_p=\left(\frac{k_p}{k_m}\right)v_M \qquad \alpha_p=\left(\frac{S_{oi_M}}{S_{oi_p}}\right)a\alpha_M \qquad r_P=\frac{S_{oi_M}(1-r_M)}{S_{oi_P}}$$

RESULTS: PREDICTION vs. ACTUAL



CHEMICAL EOR & HEAVY OIL

- Problems:
  - Unfavourable mobility ratio
  - Gravity segregation
  - Rock-fluid reactions, chemical loss, dilution
  - Lack of scaling criteria, inadequate simulation
  - Often used where steam is not suitable
- Applicable methods:
  - Surfactant flooding *unsuccessful*
  - Alkaline flooding *unsuccessful*
  - CO_2 immiscible; cyclic stimulation *LImited success with WAG*

CHEMICAL EOR OFFSHORE

- Challenges:
  - Platform space limited
  - High salinity
  - Large well spacing
  - Environmental concerns
- Likely Processes:
  - Micellar flooding
  - ASP flooding
  - Polymer flooding

- Solutions may be mixed onshore and shipped

- Constant supervision required

IMPROVED CHEMICALS

- Candidate reservoirs often have :
  - High temperature
  - High salinity
  - High water saturations
  - Low permeability
  - Clay content >5%
- Need chemicals suitable for above conditions
  - Polymers stable above 80° C and at high salinity
  - Polymers with high RF
  - Surfactant with low adsorption, tolerant of clay
  - Inexpensive chemicals coupling surfactant and polymer properties

EOR SCREENING CRITERIA

- *Most important:* geology and mineralogy

- Oil viscosity < 35 cp
- Oil API gravity > 30 API
- Permeability ≥ 100 md
- Porosity ≥ 15%
- Temperature < 150 F
- Depth < 9,000 ft
- Pressure not critical
- Oil saturation ≥ 45%
- Oil in place at process start ≥ 600 Bbl/acre-ft

- Formation sdst preferred
- Thickness 20-30 ft
- Stratification desirable
- Clay content < 5%
- Salinity < 20,000 ppm
- Hardness < 500 ppm
- Oil composition Light, intermediates & organic acids desirable
- No bottom water or gas cap

HOW TO PLAN A FLOOD

- Choose a process likely to succeed in a candidate reservoir
- Determine the reasons for success *or* failure of past projects of the process
- Research to “fill in the blanks”
  - Determine process mechanisms
  - Derive necessary scaling criteria
  - Carry out lab studies
- Field based research
- Establish chemical supply
- Financial incentives essential

PROCESS EVALUATION

- Compare field results with lab (numerical) predictions
- Relative permeability changes?
- Oil bank formation? If so, what size?
- Mobility control?
- Fluid injectivity?
- Extent of areal and vertical sweep?
- Oil saturations from post-flood cores?

INTERPRETATION OF RESULTS

- Large number of chemical floods with little technical success
- Field tests implemented for tax advantage misrepresent process performance
- Questionable interpretations distort process potential

COST OF CHEMICALS

- As the oil prices rise, so does the cost of chemicals, but not in the same proportion
- Typical Costs:
  - Polymer - $3/lb
  - Surfactant - $1.20/lb
  - Crude oil - $60/bbl
  - Caustic - $0.60/lb
  - Isopropanol - $20/gallon
  - Micellar slug - $25/bbl
- Process Efficiency: volume of oil recovered per unit volume (*or mass*) of chemical slug injected

THE CASE FOR CHEMICAL FLOODING –

- Escalating energy demand, declining reserves
- Two trillion bbl oil remaining, mostly in depleted reservoirs or those nearing depletion
- Infill drilling often meets the well spacing required
- Fewer candidate reservoirs for CO_2 and miscible
- Opportunities exist under current economic conditions
- Improved technical knowledge, better risk assessment and implementation techniques

CONCLUSIONS

- Valuable insight has been gained through chemical floods in the past – failures as well as successes

- MP and ASP methods hold the greatest potential for commercial success; polymer flooding a third option

- Chemical flooding processes must be re-evaluated under the current technical and economic conditions

CONCLUSIONS –

- Chemical floods offer the only chance of commercial success in many depleted and waterflooded reservoirs

- Chemical flooding is here to stay because it holds the key to maximizing the reserves in our known reservoirs