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MEOR DATA BASE AND EVALUATION OF RESERVOIR CHARACTERISTICS FOR MEOR PROJECTS

Topical Report

By

Rebecca S. Bryant

September 1989

Performed Under Cooperative Agreement No. FC22-83FE60149

IIT Research Institute

National Institute for Petroleum and Energy Research

Bartlesville, Oklahoma

National Energy Technology Laboratory
National Petroleum Technology Office
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MEOR DATA BASE AND EVALUATION OF RESERVOIR CHARACTERISTICS FOR MEOR PROJECTS

By R. S. Bryant*

ABSTRACT

One aspect of NIPER's microbial enhanced oil recovery (MEOR) research program has been focused on obtaining all available information regarding the use of microorganisms in enhanced oil recovery field projects. The data have been evaluated in order to construct a data base of MEOR field projects. The data base has been used in this report to present a list of revised reservoir screening criteria for MEOR field processes. This list is by no means complete; however, until more information is available from ongoing field tests, it represents the best available data to date. The data base has been studied in this report in order to determine any significant reports from MEOR field projects where the microbial treatment was unsuccessful. Such information could indicate limitations of MEOR processes. The types of reservoir information sought from these projects that could be limitations of microorganisms include reservoir permeability, salinity, temperature, and high concentrations of minerals in the rock such as selenium, arsenic, or mercury. Unfortunately, most of the MEOR field projects to date have not reported this type of information; thus we still cannot assess field limitations until more projects report these data.

INTRODUCTION

It has been estimated that more than 350 stripper wells in the United States and other countries have been injected with microorganisms for enhanced oil recovery (EOR).[1] Although a rather large number of wells has been microbially treated, information available from these field projects is scarce, and no suitable data base has been constructed. In order to alleviate this problem, another key research area in the BE3 project has been to continue to monitor all available data resulting from MEOR field projects, and to establish a data base of this information for future field applications. The accumulation of these data has provided a list of 39 projects in which

*Project Leader.

microorganisms have been used. This list of MEOR field projects is not extensive, nor all encompassing, since there are several proprietary MEOR projects for which no information is available. A revised list of screening criteria for MEOR applications has been constructed from the available information and is presented in this report.

MEOR FIELD PROJECT DATA BASE

During the past 2 years, a data base has been designed that contains all available information from MEOR field projects that have been conducted both in the United States and in other countries. The data base contains information on 39 field projects, although the information from many of these projects is incomplete. The MEOR Field Project Data Base was designed to be incorporated into the Department of Energy's EOR Project Data Base that is part of the Tertiary Oil Recovery Information System (TORIS). Two new records were incorporated into the data base: MEOR Project Info and MEOR Bacteria Info. All other data from the MEOR field data base will fit into existing records. Table 1 lists the parameters for NIPER's MEOR Field Project Data Base. There are only four field tests to date that contain information under all categories. However, all 39 projects have been incorporated.

Several of the parameters in table 1 were added specifically because of the nature of a microbial enhanced oil recovery process. These parameters include: injected microorganisms, type of microbe, spores, the microbial products - including gases, acids, polymers, solvents, surfactants and hydrogen sulfide, size of the microbe, nutrient information, indigenous microorganisms that might be present in either the reservoir, flood waters, or nutrients, and what microorganisms were recovered after the tertiary process. The other parameters will be incorporated as elements common to the Department of Energy data base, and are important for any enhanced oil recovery project.

TABLE 1. - Parameters in NIPER's MEOR Field Project Data Base

Reservoir information (pre-test)	Injection information
Well spacing, ft.	Preflush
Permeability, md	Injected microorganisms
Porosity, %	Type of microbe
Salinity, %	Spores
Temperature, °F	Gases
pH of reservoir brine	Acids
Reservoir pressure, psi	Polymers
Depth, ft	Solvents
Net pay, ft	?
Production formation zone	Surfactants
Oil field	Mutation rate
Lithology	Size, microns
Mineralogy (high amounts of some electrolytes affect microbial growth)	
	Hydrogen sulfide produced?
Oil gravity, °API	Injected nutrient
Oil saturation, %	
Reservoir Gases	Type
Oil viscosity, cp	Concentration
Number of wells	Amount
Water production, bbl/day	Injection procedure
Oil production, bbl/day	
Types of indigenous microorganisms	
Previous primary, secondary, tertiary recovery methods	
Test date	

Recovery information (post-test)
Test length, months
Soak period, days
Shut-in pressure, psi
Oil gravity, °API
Oil gravity
Oil viscosity, cp
pH of brine
Gases
Water production, bbl/day
Oil production, bbl/day
Types of microorganisms recovered
Changes in water-oil ratio

Table 2 lists the DOE data base elements for field and reservoir information on microbial EOR field projects in the United States. At this time, there are 10 field tests to be entered, and all available information has been incorporated into this data file.

TABLE 2. - Department of Energy's field and reservoir data base for USA microbial projects

	1	2	3	4	5
Field	Lisbon			LaVernia	Longwood
County	Union				Harrison
State	Arkansas			Texas	Texas
Hiperm	5,770 md			50 md	1.0 md
Porosity	31%			22%	25%
Current temp.	96° F			80° F	
Depth	2,100 ft			1,500 ft	2,600 ft
Oil viscosity				8.6 cp	10 cp
Oil gravity	36° API				40° API
Prod. form. zone	Nacatoch			Navarro	Goodland LS
Project name				Vorphal	Boynton
Lithology	sandstone, 8% carbonate			sandstone	limestone
Net pay					25 ft
So-current					17%
# Inj. wells	2			1	2
# Prod. wells	3			3	13
Operator	Mobil	Al Johnson	Petrogen	Alpha Env.	Alpha Env.
Tertiary date	1954	1977	1977	1986	1986

TABLE 2. - Department of Energy's field and reservoir data base for USA microbial projects (continued)

	6	7	8	9	10
Field		Delaware Childers	SE Vassar	Coleman	West Texas
County		Nowata	Payne	Coleman	
State		Oklahoma	Oklahoma	Texas	Texas
Hiperm		63 md	300	13	
Porosity		20%	22%	12%	
Current temp.		80° F	90° F		
Depth		650 ft	1,820 ft	2,400 ft	1,650 ft
Oil viscosity		9 cp		39 cp	43 cp
Oil gravity		34° API		35° API	
Prod. form. zone		Bartlesville sand		Vertz SS	
Project name		Mink Unit	Vertz Sand Unit		
Lithology		sandstone	sandstone	sandstone	sandstone
Net pay		30 ft	8 ft	60 ft	
So-current		31%			
# Inj. wells		4	5		19
# Prod. wells		10	14	98	18
Operator	Pure Oil Co.	DOE/NIPER/ MSC/ INJECTECH	Univ. OK/ Tenneco	Hardin-Simmons University/ PetroSciences, Inc.	
Tertiary date	1957	1987	1987	1987	1986

Only a few of the projects have provided reasonably complete data for the parameters in table 1 or 2. For example, table 3 lists the oil recovery, permeability, porosity, depth, oil viscosity, and residual oil saturation for the projects. There are many gaps in these data, and thus there are inherent problems when trying to predict trends where microbial treatments were more effective. Figure 1 presents a graph of the maximum increase in oil production reported for those field projects. These data range from 1 to 730% increases, with the average maximum increase of oil production rate being 75%.

TABLE 3. - Selected project information from the NIPER MEOR data base

Project	Maximum increase in oil production rate %	k[1]	Porosity, %	Depth, ft	Oil Visc., cp	ROS[2], %
1	250	5770	31	2100	8	
2		5500	28	164	Heavy	30
3		550	28	164	Heavy	30
4	35	5500	36	1965		
5		5500		1965	Heavy	
6		55		2293	Heavy	
7	26		13	1830		
8	82			1900		
9	2			2350	1.3	
10	67		25	1320	11	
11	11			1700	16	
12	22			1650	7	
13	77			1745		
14	65			1734	11	
15	40		11	1687		
16	12			1955	13	
17	4			2627		
18	9			1893	5	
19	0.8		11	3600		
20	22			655		
21		650		2293	43	
22	10	225		3255	3	
23	60			8042		
24	60			2293	600	
25	116	76	24	2127	5	50
26	126	87	24	2127	40	50
27	18	1000	21	3930	Heavy	55
28	7.5			3275	40	
29		900		3857		71-90
30	730		33		300	
31	30			1000	300	
32	40			3000		
33				816		
34	2-300			2100		
35	10	50	22	1500	9	
36	13	<1	25	1600	10	
37	16	62	20	630	7	31

[1]k = permeability in millidarcies.
[2]ROS = residual oil saturation.

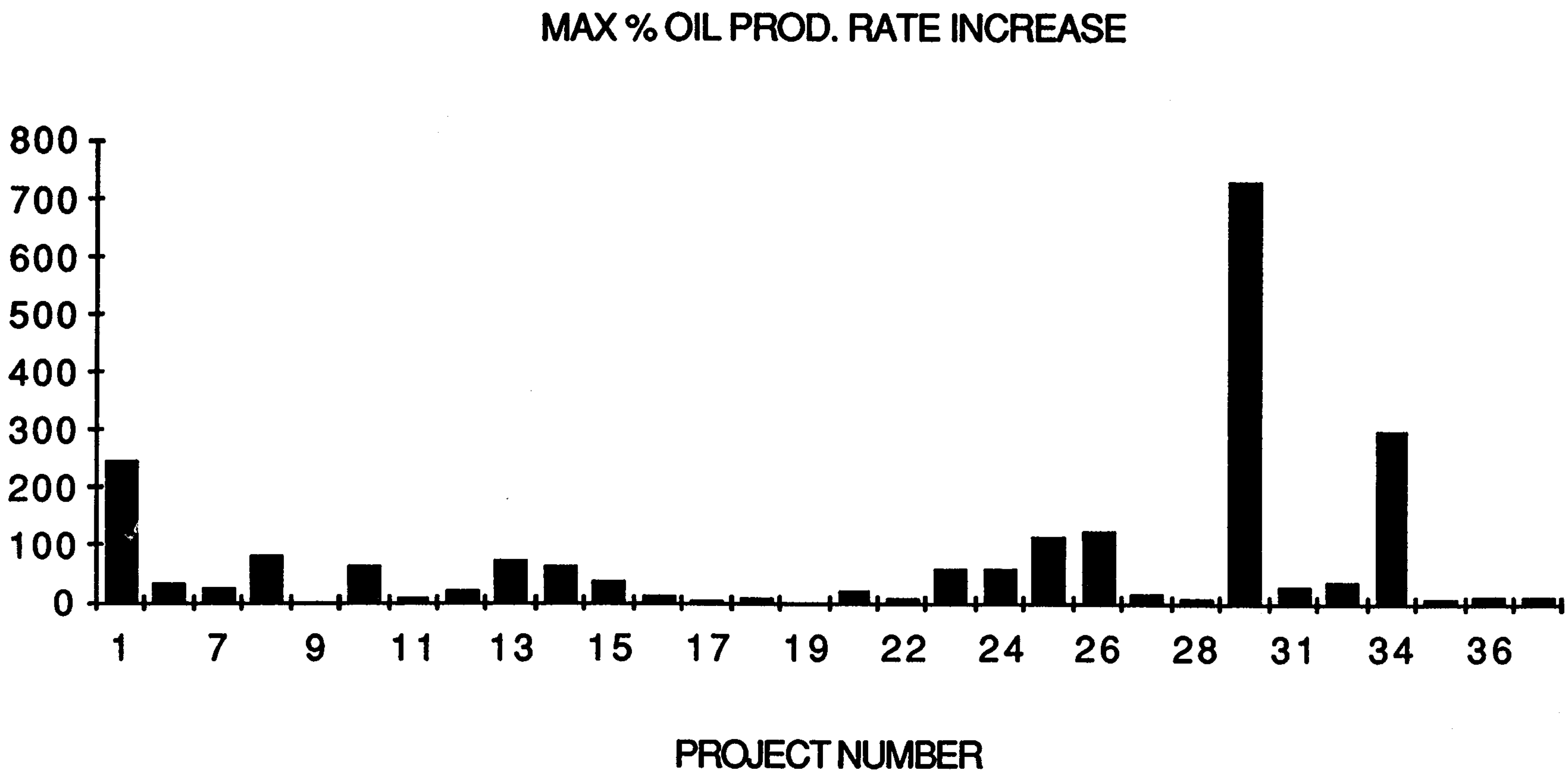

FIGURE 1. - Reported maximum percentage of oil production rate increase in designated projects.

The best documentation of a completed MEOR field project is that of a microbial injection performed in 1954 by Mobil Oil Co.[2] (see table 4.) Table 4 summarizes the information from this project as it applies to the MEOR Field Project Data Base elements (table 1). The increase in oil production was obviously attributed to microbial activity; however, in this project they did not continue to treat the well after the initial 5 month injection period. It is not

TABLE 4. - Available information from 1954 Mobil Oil Co. MEOR field test

Reservoir information (pre-test)	
Well spacing, ft	400
Permeability, md	5770
Porosity, %	31
Salinity, %	4
Temperature, °F	96
pH	?
Reservoir pressure, psi	?
Depth, ft	2100
Producing formation zone	Nacatoch
Oil field	Lisbon Field, Union County, Arkansas
Lithology	Sandstone with 8% carbonate
Oil gravity, °API	36
Reservoir gases	Methane
Oil viscosity, cp	8
Number of wells	2
Water production, bbl/day	250
Oil production, bbl/day	?
Types of indigenous microorganisms	Few, but not identified
Previous primary, secondary, tertiary recovery	waterflooded out
Tertiary date	1954
Injection information	
Preflush	Waterflood
Injected microorganisms	*Clostridium acetobutylicum*
Type of microbe	
Spores	Yes
Gases	Yes, H_2, CO_2
Acids	Yes, formic, caprylic, etc.
Polymers	None
Solvents	Yes, ethanol, butanol, acetone
Surfactants	?

TABLE 4. - Available information from 1954 MOBIL MEOR field test (continued)

Injection information (continued)	
Mutation rate	Unknown
Size, microns	1.5
Hydrogen sulfide produced?	No
Nutrient - beet molasses	4000 gallons of 2% by weight
Recovery information (post-test)	
Test length, months	12
Soak period, days	?
Shut-in pressure, psi	?
Oil API gravity	?
Oil viscosity, cp	?
pH of brine	?
Gases	CO_2, 80% increase in methane
Water production, bbl/day	500
Oil production, bbl/day	3.1
Types of microorganisms recovered	No *C. acetobutylicum*, other species were found
Comments	Maximum increase in oil production rate of 250%, abandoned

known how long any production increase was observed. They reported that they probably stimulated an indigenous population of *Clostridium* by molasses injection, or the *Clostridium* contaminant was already present in their molasses. This species of *Clostridium* was not the one that they had injected, although some of the products of its metabolism were the same, including carbon dioxide. They found an increase in methane and carbon dioxide after the microbial injection, and later it was reported that they observed some ethanol at the producing wells.[3]

Two single well MEOR field projects sponsored by the Department of Energy were initiated in 1986.[4] NIPER provided supporting laboratory work for these projects, and therefore obtained information on these two projects. Table 5 summarizes the available data. Although production data are still being obtained, Alpha Environmental, Inc. has reported an increase in oil production from both projects. Although the oil viscosity was very similar, the two fields used for these MEOR single well injections were very different in lithology.

TABLE 5. - Data obtained from the Department of Energy MEOR field projects

Project 1 - Alpha environmental single well field test #1

Reservoir information (pre-test)

Well spacing, acre	10
Permeability, md	50
Porosity, %	22
Salinity, %	1.0
Temperature, °F	80
pH	7.2
Reservoir pressure, psi	700
Depth, ft	1500
Producing formation zone	Navarro
Oil field	Martin Vorphal Lease, LaVernia, TX
Lithology	Sandstone with shale layers
Oil gravity, °API	31
Reservoir gases	none
Oil viscosity, cp	8.6
Number of wells	1 injector, 6 producers
Water production, bbl/day	?
Oil production, bbl/day	4.6
Types of indigenous microorganisms	?
Previous primary, secondary tertiary recovery	?
Tertiary date	1986

Injection information

Preflush	none
Injected microorganisms	ALPHABAC & ALPHACAT - 8 lbs dried
Type of Microbe	Proprietary
Spores	No
Gases	None
Acids	Yes
Polymers	None
Solvents	None
Surfactants	Yes
Mutation rate	Unknown
Size, microns	1.0
Hydrogen sulfide produced?	No
Nutrient	Nitrate, Phosphate

Recovery information (post-test)

Test length, months	6
Soak period, days	5
Shut-in pressure, psi	?
Oil API gravity	31
Oil viscosity, cp	9.0
pH of brine	7.0
Gases	none

TABLE 5. - Data obtained from the Department of Energy MEOR field projects (continued)

Recovery information (post-test)

Water production, bbl/day...?
Oil production, bbl/day..3.88
Types of microorganisms recovered
...........................Reported that they recovered their microbes
Comments
....Slight decrease in oil production rate according to reported figures

---

Project 2 - Alpha Environmental, Inc. single well field test #2

Reservoir information (pre-test)

Well spacing, acre...10
Porosity, %..25
Salinity, %...4.0
Temperature, °F..90
Brine pH..7.3
Reservoir pressure, psi...?
Depth, ft..1600
Producing formation zone...................................Goodland
Oil field ....Boynton Heirs Lease, Longwood Field, TX
Lithology...Limestone
Oil gravity, ° API...32
Reservoir gases..none
Oil viscosity, cp..10
Number of wells........................2 injectors; 14 producers
Water production, bbl/day...?
Oil production, bbl/day...5.9
Types of indigenous microorganisms.......................Unknown
Residual oil saturation, %.......................................17
Previous primary, secondary, tertiary recovery...................?
Tertiary date..1986

Injection information

Preflush..none
Injected microorganisms..........ALPHABAC & ALPHACAT, 8 lb/well
Type of microbe..Proprietary
Spores...No
Gases..None
Acids...Yes
Polymers...None
Solvents...None
Surfactants...Yes
Mutation rate...unknown
Size, microns...1.0
Hydrogen sulfide produced?.....................................No
Nutrient..........Nitrate and Phosphate, commercial fertilizer

TABLE 5. - Data obtained from the Department of Energy MEOR field projects (continued)

Recovery information (post-test)

Test length, months	6
Shut-in pressure, psi	?
Oil API gravity	32
Oil viscosity, cp	5.8
Brine pH	6.8
Gas composition	None
Water production, bbl/day	?
Oil production, bbl/day	6.8
Types of microorganisms recovered	Reported that ALPHABAC was recovered
Comments	24% reported increase in oil recovery

The microorganisms used for this field test are collectively known as ALPHABAC, and were injected without any nutrient or carbon source. Alpha Environmental claims that ALPHABAC can metabolize crude oil for its energy, and utilize a proprietary catalyst, ALPHACAT, for its oxygen source, since these bacteria are strictly aerobic (oxygen-requiring). These single well tests were injected by gravity siphoning, a method which has not been used by any other reported MEOR field test. This method did not require any shut in period for the wells. It was reported by Alpha Environmental that the injected microorganisms have been observed in producing wells on both of these projects, as much as 1,500 ft away from the injection well.[3] If this occurred, it may indicate a microbial transport phenomenon or be the result of a geological anomaly in the reservoir.

A microbial-enhanced waterflood project was initiated by NIPER in 1986 and sponsored by the U.S. Department of Energy, and two industrial participants. A baseline of oil production, and laboratory measurements was established prior to microbial injection.[5] Microorganisms were injected into four injection wells March 19 and 23, 1987; the wells were put back on production April 3, 1987. Ten wells surrounding the four injectors are being monitored on a weekly basis for water-oil ratio, pH, total dissolved solids (TDS), trace mineral constituents, microorganism and molasses concentrations, surface and interfacial tensions, and oil viscosity and gravity. The data from this project are listed in table 6.

Table 6. - Data obtained from the Department of Energy MEOR field projects

Project 3 - NIPER, MSC, INJECTECH - MEOR waterflood experiment

Reservoir information (pre-test)

Well spacing, acre	5
Permeability, md	52
Porosity, %	20
Salinity, %	<0.02
Temperature °F	80
Brine pH	6.8
Reservoir pressure, psi	535
Depth, ft	600
Producing formation zone	Bartlesville Sand
Oil field	Delaware-Childers near Nowata, Ok
Lithology	sandstone
Oil gravity, ° API	35
Reservoir gases	Methane - 77.6%; CO_2 - 15.8%
Oil viscosity, cp	7.0
Number of wells	4 injectors out of 21 were treated, 15 total producers
Water production, bbl/day	620
Oil production, bbl/day	6.4
Types of indigenous microorganisms	Few sulfate reducing bacteria; some *Bacillus*
Residual oil saturation, %	31
Previous primary, secondary, tertiary recovery	Ongoing waterflood
Tertiary date	1987

Injection information

Preflush	None
Injected microorganisms	NIPER Bac 1, 100 lb/well
Type of microbe	2 *Bacillus*, 1 *Clostridium*, 1 facultative anaerobe
Spores	Yes
Gases	Yes, CO_2
Acids	Yes, butyric, valeric, etc.
Polymers	None
Solvents	Yes, butanol, acetone, etc.
Surfactants	Yes
Mutation rate	Unknown
Size, microns	1.5
Hydrogen sulfide produced?	No
Nutrient - OKC Molasses (cane)	25 gallons/injection well

TABLE 6. - Data obtained from the Department of Energy MEOR field projects (continued)

Recovery information (post-test)	
Test length, months	3
Soak period, days	12
Shut-in pressure, psi	550
Oil viscosity, cp	6.5
Oil API gravity	35
Reservoir pH	6.5
Gas composition,%	methane, 60
CO_2	25.8
Butane	2.8
Pentane	2.6
Octane	3
Water production, bbl/day	620
Oil production, bbl/day	7.5
Types of microorganisms recovered	Others stimulated by molasses; some NIPER Bac 1
Comments	About 19% increase in recovery at tank battery (as of 7/15/87)

DESIGN OF AN MEOR FIELD PROJECT

In both single well and waterflood MEOR projects, successful microbial injection has been reported.[5-6] Although there is a broad range of reservoir conditions where microbial EOR has been used, a reasonably complete set of data is available for only a few field tests. Because the information in the data base is limited, it cannot as yet be used to establish a reliable set of screening criteria for applying MEOR processes. The information can, however, be used to determine some of the critical parameters for applying microbial enhanced oil recovery processes to a particular reservoir. Any MEOR field project should be uniquely tailored to the target reservoir. This is the primary criterion for a field project. A microbial formulation must be selected that is able to grow and produce the desired metabolites under the reservoir conditions. This means that compatibility studies between reservoir fluids and rock must be conducted with the microorganisms and with the nutrients to be used. There are several reasons for compatibility testing: (1) to determine if the microorganisms can tolerate the salinity of the formation water; (2) to determine if there are any toxic metal ions or mineral constituents present in the fluid or leachable from the rock; (3) to determine if the microorganisms can grow and produce metabolites in the presence of the crude oil; and (4) to determine if there are any microorganisms already present (indigenous) in the formation or in the nutrient that will "out-compete" or interfere with the injected microbial formulation. A second important criterion for a successful MEOR field project is that the microorganisms not only grow under the selected reservoir conditions, but that they produce the correct types of metabolites that will improve oil mobilization under the reservoir conditions. In order to determine this, some prior knowledge of what mechanisms for oil mobilization are required must be obtained. Microorganisms can produce a wide variety of chemicals that may assist in enhanced oil recovery. Such chemicals include gases, acids, alcohols, solvents, surfactants, and polymers. It is important to design an MEOR field pilot project for the type of oil mobilization mechanism(s) desired. For example, if there appears to be an obvious channeling problem in the reservoir, it would be advantageous to use a microbial formulation that will help to improve sweep efficiency, and thus a polymer-producer would be selected. If a single well injection is going to be used in a huff and puff mode, then perhaps gas production for increased pressure will be most important. In the current MEOR waterflood project, it was felt that a surfactant and alcohol producer could assist in mobilizing trapped oil left after waterflooding.

Transport studies are also important in design of an MEOR field project. In some cases, such as an ongoing waterflood, it is crucial that the microorganisms and/or their metabolites transport through the formation, and not just remain stabilized around the wellbore. Although some studies have been done relating to microbial transport,[7] there are still several unanswered questions. The permeability and porosity ranges that limit microbial processes are still unknown. Successful MEOR field projects have been reported in permeabilities ranging from <1 to 5,770 millidarcies. This certainly may be possible, but there is not enough data to really support this wide range. Since only two field tests have been reported in <50 md permeability, this figure appears to be a reasonable lower limit. Knowledge of microbial and metabolite transport will also assist in monitoring and evaluating an MEOR field project. In the case of a MEOR waterflood, the metabolites should be detectable in the monitored wells. The nutrient and microbes themselves may also serve as tracers for the project. If the goal of the field project is to improve sweep efficiency only, then injectivity and nutrient concentrations are probably more important than microbial metabolite production and transport. The microbes or the polymer they produce will be used to selectively plug high permeability zones and divert the fluid. Whereas, in a microbial waterflood, their products such as surfactants and alcohols, move the oil.

A list of reservoir screening criteria for MEOR field projects is difficult to present with the current available information. Certainly there are some reservoirs where conditions are not amenable for MEOR. For this reason, two lists are presented in table 7; the first list encompasses the reservoir properties that are limiting for microbial processes at the present time, and the second list presents reservoir parameters that require further definition. It is generally accepted among microbiologists that most commonly used microbes for field tests have a salinity tolerance of less than 10%. This is why this figure was selected. Microbes generally average 1-2 microns in length, and therefore the pore throat size must be greater than this figure. Future work and data should be focused on closing the gaps between these two lists, and enable MEOR technology to become more applicable.

ENVIRONMENTAL ASPECTS OF MEOR

Work at NIPER since October 1983 has been directed towards determining any potential environmental hazards that may result from the injection of microorganisms in oil field applications. Results from these studies have indicated that the injected microbes must be tested under actual reservoir conditions to determine if potential environmental hazards could result from injection. Assessment of the potential environmental impact of injecting microorganisms should include the following: (1) actual environmental studies must be conducted concurrently with the MEOR field project; (2) waste disposal methodology must be considered; (3) the project and off-pattern wells must be monitored to ensure that the microbes do not migrate out of the targeted well pattern; (4) some knowledge of the microbial metabolites that will be produced in the reservoir must be obtained; and (5) water from any nearby drinking water wells should be monitored.

TABLE 7. - Revised screening criteria for MEOR field projects

Limiting Reservoir Properties for Microorganisms	
Salinity	>10% (>100,000 ppm)
Temperature	>160°F
Trace minerals	Toxicity for microbes varies, but includes arsenic, nickel, selenium, etc. 5-10 ppm
Pore throat size	<1-2 microns
Other Reservoir Parameters for MEOR Requiring Further Definition	
Oil Gravity	>20 API; few heavy oil tests done
Permeability	>50 millidarcies
Indigenous microorganisms	Must be compatible with injected microbes
Well spacing	Unknown; probably closer would be better
Injection Pressures	Unknown

SUMMARY

Microbial enhanced oil recovery (MEOR) technology has made significant advances in a relatively short period of time. Laboratory research has shown that microorganisms can produce chemicals which mobilize oil, transport in porous media, and adapt to a variety of seemingly adverse environmental conditions. Field applications have begun, but the task of determining how to apply the technology to give optimal oil recovery still remains. Basic laboratory research has contributed to knowledge of MEOR processes, but the technical and economic feasibility of applying the technology still needs to be addressed. More well-documented and designed field projects should be done to provide much needed information for reservoir screening of MEOR processes, as well as improving the predictability of the MEOR technology.

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