MEOR / MIOR

Microbial Enhanced Oil Recovery / Microbial Increased Oil Recovery
RAM Biochemicals, Inc. - 1991

INTRODUCTION

"Many options are available to oil producers interested in microbial enhanced oil recovery (MEOR). Because of the nature of microbial growth and the ability of micro-organisms to utilize relatively inexpensive chemicals as nutrients, the economics should be attractive under almost any circumstances."[1]

There remains little doubt that MEOR can be a successful, cost effective approach to enhanced oil recovery particularly when applied to stripper well production. But how does a producer choose from among the various microbial processes now available? What screening criteria are used to determine a suitable candidate well or reservoir? What procedures are recommended to evaluate a well or field for MEOR, and what amount of return will the dollars invested in MEOR actually deliver?

I. SELECTING A MICROBIAL PROCESS FROM THOSE CURRENTLY AVAILABLE

Of the six microbial processes identified by the National Institute for Petroleum Energy Research (NIPER), well stimulation, well bore cleanup, enhanced water flooding, and mitigation of coning are available commercially from a growing number of MEOR service companies. According to Dr. Rebecca Bryant, Biotechnology Project Leader at NIPER, a microbial process can be selected to address one of several production problems by first defining the problems, and then determining the types of microbial products needed to overcome them. When the types of microbial products (bio-chemicals or gasses) are known, a microbial mix can be selected that will produce them. Then, an MEOR processes utilizing that microbial formulation is chosen from among those currently available. MEOR process selection is based upon specific well or reservoir parameters such as permeability, temperature, depth, salinity, and API gravity.[2]

Editor's Note: *Use Table 1 or narration or both, which ever you prefer. NIPER's classification of different microbial reservoir treatments is shown in Table 1. The contents of this table appear in narrative form in the Section I(a), entitled – "Production problems and microbial processes."*

MICROBIAL WELL STIMULATION

Currently available microbial processes offer a variety of approaches to address various production problems. Problems such as lack of reservoir pressure and poor injectivity are addressed by the microbial well stimulation method. This process typically uses an initial injection of micro-organisms suited to life down hole followed by periodic additions of a fermentable nutrient medium to sustain the in situ production of CO_2, alcohol, organic acids, and surfactants for weeks to months. Bio-chemicals and gasses are produced by microbial growth and they help mobilize the oil trapped in the near-well bore by capillary forces.

A relatively new microbial well stimulation process developed by RAM Biochemicals, Inc. uses a suspension of anaerobic micro-organisms, nutrient, bio-surfactants, and catalysts intended to utilize hydrocarbon sources in the reservoir. This process is geared to the production of methane and ethane rather than carbon dioxide thus eliminating the need for large, periodic injections fermentable nutrients. It also averts the loss of Btu value in any co-produced gas as might be caused by CO_2 generation. Other factors influencing RAM's decision to take this approach are; 1) reservoirs are generally anaerobic (lacking in oxygen), 2) anaerobic bacteria can tolerate extremes of temperature, pH, salinity and solvent contamination, and 3) anaerobes produce a large number of "oil releasing" metabolite products.[3]

Still other well stimulation methods attempt to increase oil production by stimulating indigenous microbial populations with various nutrients, micro-nutrients, or biocatalytic agents (usually proprietary in nature). According to NIPER, most successful well stimulations can be attributed to the use of micro-organisms that produce gas and surfactants.

MICROBIAL WELL BORE CLEANUP

Microbial well bore cleanup processes generally use oxygen-utilizing micro-organisms and require regular treatments (weekly to monthly) to overcome the hostile down hole environment as their activity is short-lived. The microbes attack and digest (degrade) paraffinic or asphaltic deposits in the well bore allowing them to be easily removed. Injectivity can be greatly improved by the emulsifiers, surfactants, and acids these micro-organisms produce.

Editor's Note: *As reported in our March, 1991 issue Micro-Bac International, Inc., Alpha Environmental, both of Austin, Kiseki Technology, Inc. of Calgary, Alberta, and the Great American Bacteria Company produce microbial paraffin control products and have MEOR technology; added to the growing list are; Petroleum Bioresources, Microbial System Corporation, Microbios Ltd., Microbes Research & Development, Geo-Microbial Tech, Inc., National Paraclean, Universal Paraclean, Inc., and PSL, Inc.*

MICROBIAL ENHANCED WATERFLOODING

Microbial enhanced water flooding targets oil trapped in the reservoir due to capillary forces. This common production problem can be overcome by using micro-organisms capable of moving through the reservoir and producing bio-chemicals to mobilize the trapped oil. Surfactants reduce oil/water interfacial tension (IFT) and cause emulsification. They can also increase production by altering the relative permeability of rock to oil by changing the surface wettability of the rock. Biogases (CO_2, N_2, H_2, and CH_4) improve oil recovery by increasing reservoir gas drive, reducing oil viscosity and swelling, and making oil more mobile. In carbonate formations or sandstone with carbonaceous cementation, acid-producing microbes can recover oil by increasing permeability.[4]

II. RESERVOIR SCREENING

NIPER's work indicates that 31% of reservoirs in the major oil-producing states of the U.S. have potential candidates for microbial enhanced oil recovery (MEOR) processes."[5] This figure agrees with a 1981 computer survey by Clark, etc. al. made of 45,000 to 50,000 reservoirs in the top 9 U.S. oil-producing states which reported that 27.2% had environmental conditions favorable for microbial growth. Texas leads the oil producing states with 134 reservoirs fitting the MEOR screening criteria. Next comes California with 106, then Colorado, Louisiana, and Wyoming with 28. Kansas has 18.[6]

III. SELECTION CRITERIA FOR CANDIDATE OIL WELLS & FIELDS

Table 2 - Selecting MEOR Candidate Wells (See: Appendix) – This table was compiled by combining data obtained from NIPER, B. Bubela, and RAM Biochemicals, Inc. A narrative of the selection process appears below.

Editor's Note: Use Table 2 or the narrative below to determine the likelihood that a well or field is a candidate for MEOR treatments. The most important reservoir criteria are those related to microbial growth such as temperature/depth, salinity (TDS), concentration of trace minerals and heavy metals, permeability, and the make up of the indigenous microbial population.

TEMPERATURE: AVERAGE CUTOFF POINT - 75^{O}C (170^{O}F)

OPTIMUM RANGE: 35 TO 50^{o}C (100 TO 120^{o}F)

NOTE: Some costal U.S. reservoirs have a cutoff point as high as 80^{o}C (175^{o}F) and in Southeast Asia it is as low as 54^{o}C (130^{o}F).

PRESSURE: 10 TO 300 ATMOSPHERES

Pressure and temperature are directly related; temperature increases about 2.7^{o}C per 100 meters of depth. The average cutoff temperature of 66^{o}C corresponds to a depth of approximately 1700 meters (5,580 ft.). Normal strata at this depth is pressurized to about 160 atmospheres while over pressurized strata can run 300 atmospheres or more. Pressure affects both the growth rate and the metabolic activity of microorganisms, but far less than temperature.

SALINITY: FRESH WATER TO 150,000 PPM (15%)

One-half of the world's major oil deposits have salinity concentrations low enough for Wel-Prep

5 treatments. That is, microbial growth is only minimally affected by the concentration salt ions below 150,000 PPM.

Sandstone formation waters average around 25,000 ppm salts (2.5%), and carbonate reservoirs average about 90,000 ppm (9.0%). However, reservoir waters vary markedly in their cation and anion composition. Salinity can not be looked at alone because its effects on microbial growth are compounded with pressure and temperature. This interaction with other growth factors can greatly influence the release of oil and gas.

FORMATION MINERALOGY - IN ORDER OF TREATABILITY

CARBONATE FORMATIONS (LIMESTONE, CHALK, DOLOMITE)
CONSOLIDATED SANDSTONE
UNCONSOLIDATED SANDSTONE
GRANITE, GRANITE WASH
OTHER

POROSITY: 3 TO 30%

Porosity is the ratio of the pore and fracture volume to the total volume of reservoir rock.

PERMEABILITY: > 50 MILLIDARCIES

Permeability is a measure of oil flow through reservoir rock due to a pressure gradient. Sandstone and limestone strata can range in permeability from 0.1 to thousands of millidarcies. The extent to which void spaces are interconnected and the minimum size of the interconnecting channels are determining factors of permeability.

pH: BETWEEN 5 AND 9

API GRAVITY: 15^{o} OR GREATER

API Gravity is an index of specific gravity of oil developed by the American Petroleum Institute. Texas benchmark crude has an API Gravity of 42^{o} while some asphaltic oils are 20^{o} or less.

TYPICAL CANDIDATE WELL OR RESERVOIR

Temperature	=	35 - 50°C (100 -120°F)
Depth	=	1,000 meters (3,200 ft.)
Porosity	=	> 10%
Permeability	=	> 150md
Injectivity	=	Good
Salinity	=	< 10%
pH	=	6 - 8
Type Formation	=	Carbonate
Oil Type	=	Paraffinic
API Gravity	=	> 30 - 40°
Oil Saturation	=	> 25%

IV. EVALUATION PROCEDURES

For single well MEOR treatments, simple compatibility studies between reservoir fluids and microbial mixtures may be adequate to predict whether a given microbial process can be applied successfully. The tests are usually test tube experiments in which several microbial formulations are grown in the presence of reservoir fluids and sometimes reservoir rock. Microbial growth characteristics and metabolite production are measured to determine the optimal set of conditions. Compatibility tests can determine potential mechanisms for increasing oil production, test for salt tolerance, or assess microbial growth under simulated reservoir conditions by elevating temperature and pressure, or adding indigenous micro-organisms.

When considering a more extensive multi-well or field flood project, the producer would benefit from core flooding studies, or better still, a single-well injectivity test. If injectivity is unaffected after the microbial injection, then permeability may not be a limiting factor for that reservoir.[7]

V. COST EFFECTIVENESS OF MEOR PROCESSES

Field trials involving several MEOR processes were summarized by Hitzman [1982] and despite the limited documentation available some encouraging results were reported: 1) increases in oil production of 100 to 300% were observed in some cases; 2) none of the trials reported significant decreases in production; 3) the processes were inexpensive, with the major costs incurred for field preparation.[8]

(a) Single Well MEOR Projects

A single well project using either microbial well bore cleanup or well stimulation offers the most direct method of determining cost effectiveness. A simplified view looks at dollars spent on the MEOR process vs. dollars recovered in additional oil. Above all the dollars in - dollars out method requires accurate historical records for both oil production, chemical or other service treatments, and maintenance costs. Record keeping must be equally precise beginning with the first MEOR treatment. When production flows into a common tank the producer should perform individual barrel tests to assess the results accurately.

Value added benefits to MEOR are often more subtle and more difficult to calculate than production increases, but potentially of greater valuable to the producer. Value added benefits reported by RAM and others include: oil and gas improvements (beneficiation) such as higher API gravity (the basis for the sales value of oil), higher Btu values, or increased gas production. Changes in the oil/water ratio, reduction of paraffin problems, lower overall service and maintenance costs, cleaner BS&W, tank bottoms and lead lines, lower chemical costs for corrosion and scale inhibitors, and improvement with sour gas problems have also been reported.[9]

Not to be overlooked by oil producers are the tax advantages afforded qualified tertiary recovery projects at the local, State and Federal level. In come cases, tax savings on severance taxes alone can pay for the total cost of an MEOR program.

(b) Field Flood MEOR Projects

[Insert narrative on field flood applications]

VI. PAYOUT

Table 3 - Payout Chart - shows the calculated payout for a single well at various production increases and treatment costs with oil selling at $20.00 bbl. A net return of $8.00 per barrel of oil is used and no dollar value was given for any value added benefits. From it we see a 2 barrel per day increase would payout a $300 treatment in about 19 days.

RAM Biochemicals' MEOR process like those using fermentable nutrients is cyclic in nature and designed to establish and maintain a microbial population down hole beneficial to oil production. Often, this can not be accomplished with a single treatment. Performance data shows approximately 55 to 60% of properly screened candidate wells respond RAM's MEOR process. Of these, about 35% show an initial response, 50% respond after the second treatment, and over 75% respond with three or more (cyclic) treatments. The treatment interval for cyclic MEOR is based upon each well's response characteristics over time. A 45 to 90 day maintenance schedule using smaller treatment levels than the initial treatment is the norm, according to RAM.

Calculating the payout for multi-well and enhanced water flood projects increases in difficulty in proportion to the size and scope of the project. However, the same rules concerning accurate historical records and good real-time record keeping apply. Because of the complexity of determining the return on MEOR dollars invested, RAM Biochemicals favors a lease management approach or "Total Job Concept" to MEOR. Embodied in this approach is sum total of production operations affected by the MEOR process. Value added benefits and tax benefits, not just additional oil production, are included in the equation. Ram believes this comprehensive strategy yields a more accurate measure of a project's true success or failure.

(a) Current EOR (non-microbial) Recovery Costs

EOR recovery costs vary greatly because they fluctuate with the price of oil. By extrapolation from various sources, they appear to range from $10 to $45 per barrel of oil produced with injection costs accounting for $3 to $35 of the per barrel cost.[10-11]

(b) MEOR Recovery Costs

Industry figures show the recovery costs for successful MEOR projects range from $0.20 to $15 for each additional barrel of oil produced.[12]

(c) Case Histories

BEST CASE - One of RAM's best case histories is the 9 well Osbourn lease located in Hamilton County, Illinois and producing from the Tompsonville Pool. Two wells on the lease (the #2 and #4) were each treated on 11/15/90 with 1/2 drum of Wel-Prep 5. Pre-treatment lease production averaged 10 BOPD and both wells treated had paraffin problems requiring frequent work over. Immediate post treatment production went to 20 BOPD and it was holding at 18 BOPD as of 06/15/91. Additionally, the #2 Osbourn developed substantial gas pressure where none existed before. The two wells would normally have required 3 or 4 pulling jobs in an 8 month period. None have been required since treatment. Total treatment costs were about $800. Payout @ $8.00 net return per additional barrel produced took 17 days (7 days to recover the 70 barrels "lost" during shut-in, and 10 days to recover treatment costs - 100 additional barrels). As of 06/15/91, the lease is $14,500 ahead on increased oil production and has saved approximately $8,000 on normal pulling costs.

NORMATIVE CASE - more typical of the norm is the 26 well L. Jack Gross MEOR field project in Hutchinson & Carson Counties, Texas. In three years of cyclic treatments, total oil production has increased 25% from 670 BOPM to 840 BOPM, work over costs have decreased by about 35%, and sales value has been added to both the oil (higher API gravity) and the co-produced gas (higher Btu value). Net operating profit has increased about 17%.

WORST CASE - of 12 wells in south central Texas (9 near Imperial, 2 near Big Lake, and 1 at Ft. Stockton) only one well responded. 11 of the wells were single treatments and have not been retreated as 07/25/1991. The lone well near Ft. Stockton went from 0 MCF gas before to 15 MCF after initial treatment, tapering off slowly over the following 45 days. A second treatment brought gas production back up to 6-8 MCF. This volume of gas is not believed to have been generated by microbial activity, but rather from the removal of blockage from an existing gas channel in the oil producing zone.

VII. FEDERAL INCOME TAX AND ENHANCED OIL RECOVERY

Aroused by the oil panic of the late 1970's Congress and the Department of Energy undertook a series of steps to encourage domestic production and decrease our nation's dependence on foreign oil. These steps included relief from price controls, the Windfall Profits Tax for enhanced oil recovery, and codification of current deductibility for tertiary injectant expenses (Code Sec. 193).

With the collapse of the oil and gas market, the end of price controls and repeal of the Windfall Profits Tax in 1988, EOR projects lost much of their political and economic urgency. That sense of urgency, rekindled by the Gulf Crisis, caused the oil industry to once again look at the potential of EOR. Congress again responded with enactment of a new Enhanced Oil Recovery Credit (the "EOR Credit") (Code Sec. 43) as part of the Omnibus Revenue Reconciliation (the "1990 Tax Act"). Those involved with EOR projects will find additional provisions of the 1990 Tax Act to be of interest, namely; the extension of the unconventional source fuel credit (the "Section 29 Credit") and the increase in the applicable percentage depletion for stripper well and heavy oil production.

(a) The EOR Credit

The EOR Credit is available for any "qualified EOR project". It provides the taxpayer a tax credit equal to 15% of its "qualified EOR costs" for the year and is to be deducted from the taxes otherwise owed. Being one of several tax credits included in the General Business Credit {Code Sec. 38(a)}, the EOR credit is subject to certain limitations in its availability {Code Sec. 38(c)}.

Qualified EOR costs entitled to the Credit include: (1) depreciable tangible property which is an integral part of a qualified project; (2) intangible drilling and development costs (IDC's) entitled to Code Sec. 263(c) treatment which are incurred in connection with a qualified EOR project; and (3) qualified tertiary Injectant expenses deductible under Code Sec. 193. The EOR Credit is ratably reduced over a $6 phase-out range in any year in which the preceding year's "reference price" (the average per barrel wellhead price of domestic crude oil as published by the IRS) is greater than $28 (adjusted for inflation). The 1990 reference price is $20.03.

Use of the EOR Credit in any given year and with respect to a given project may impact the availability of other tax code provisions. Specifically, tertiary Injectant costs deductible under Code Sec. 193 {Code Sec. 43(d)(1)}, and the Sec. 29 Credit for oil produced from shale or tar sand. To avoid the impact of these limitations when applicable, the taxpayer may elect to have the EOR Credit not apply for any year {Code Sec. 43(e)}.

(b) Qualified Tertiary Recovery Projects

The term "tertiary recovery method" was defined in energy regulations in effect in June 1979 (now repealed) which listed 9 distinct recovery methods.

It was to these definitions that the tax Code Sec. 193(b) and Windfall Profit Tax referred. As drafted, "the EOR Credit" (Code Sec. 43) referenced Code Sec. 193(b)'s definition of "tertiary recovery methods" which in turn referenced back to the 1979 definition with one addition. For the purposes of the EOR Credit, the following recovery methods are now qualified: (1) miscible fluid displacement; (2) steam drive injection; (3) microemulsion, or micellar emulsion flooding; (4) in situ combustion; (5) polymer augmented water flooding; (6) cyclic steam injection; (7) alkaline (or caustic) flooding; (8) carbon dioxide augmented water flooding; (9) immiscible carbon dioxide gas displacement; (10) immiscible non-hydrocarbon gas displacement; and (11) any other method for which a taxpayer obtained IRS approval under Code Sec. 193. Assuming that a project uses an approved recovery method, a petroleum engineer must certify to the IRS that the project meets the various requirements of Code Sec. 43 for the project to be entitled to the EOR Credit.

(c) MEOR as Qualified Tertiary Recovery

Although microbial enhanced oil recovery (MEOR) is recognized as a tertiary recovery method by every authoritative text on enhanced oil recovery, it is conspicuously absent from the Code. Sec. 193 definition. The IRS is well aware of this and is presently considering expanding the universe of qualifying recovery methods beyond those currently defined to cover various microbial injection and gel polymer recovery methods which were not in existence in 1979. At present, however, the Service does not appear inclined to include MEOR among the "pre-approved" methods because, in their view, such methods have not yet been commercially proven.

Current IRS thinking would provide a vehicle for qualifying MEOR projects by "Revenue Ruling", or any specific MEOR project by private letter ruling. The taxpayer requesting a private letter ruling would have to show that the use of MEOR would likely result in more a marginal increase in commercial production. This request would be reviewed by the IRS following its normal private ruling procedures and under appropriate circumstances, a specific MEOR project could then be qualified as an EOR entitled to the EOR Credit and the Sec. 193 deductions for Injectant expense.

(d) Qualification at the State level.

By Federal mandate, Governors in each oil producing state designated an appropriate State agency to process and rule on applications involving requests for tertiary recovery project status. Understandably, the various state jurisdictional agencies have followed the Federal guidelines for defining and qualifying such projects. It comes as no surprise that MEOR remains a black hole in most oil producing states.

The qualification process varies from state to state. Typically, a formal filing and request for tertiary qualification is made with the State Corporation Commission, or in Texas, the Railroad Commission. The oil producer must show that the project is designed to improve oil recovery, its designated area boundary, and that it is a new project. The services of a petroleum engineer can be most helpful in the qualification process. Once qualified, a tertiary project is often afforded tax considerations at the State, and often County level. These may include; State Severance Taxes, and County Ad Valorem Taxes. In Kansas, for example, savings on State Severance Tax alone can amount to $1,500 to $1,700 per year <u>per well</u>!

VIII. PENDING FEDERAL LEGISLATION

Congressman Wayne Owens (D-Utah) introduced legislation on February 28, 1991 that would provide Federal tax incentives for, "any method of cyclic microbial injection, or microbial enhanced water floods ..." H.R. 1199 is presently before the Committee on Ways and Means. In parallel action, the wording of this bill was combined with clean fuel and other energy related legislation to create a more comprehensive bill in support of our National Energy Policy. The combined bill, H.R. 2960, sponsored by Congressman Synar (D-Oklahoma), has been referred to the Committee on Energy and Commerce.

In support of their legislation, Representatives Synar and Owens requested a DOE study through the Tertiary Oil Recovery Information System (TORIS) which estimated an additional 1.5 billion barrels of oil could be recovered <u>via</u> enhanced recovery methods over the next 20 years. According to the study, implementing the proposed EOR tax incentives would have a neutral or slightly negative impact on Federal tax revenue, but oil producing states would net 1 to 3 billion dollars in additional revenue, and 4 to 13 thousand new jobs would be created.

SUMMARY

The promise of increased oil production offered by MEOR continues to fire the imagination and excite the curiosity of major and independent oil producers a like. Identification of the production problems, proper screening and thorough evaluation of candidate wells and reservoirs, choosing the proper MEOR process, taking full advantage of existing tax law, and following a carefully structured lease management approach will determine the ultimate success of your MEOR project. The return on investment in MEOR can be considerable.

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Operations, for their MEOR field trial data, Dr. Rebecca S. Bryant for her suggestions and review of MEOR screening criteria, and NIPER for allowing us to reproduce their MEOR classification in Table 1.

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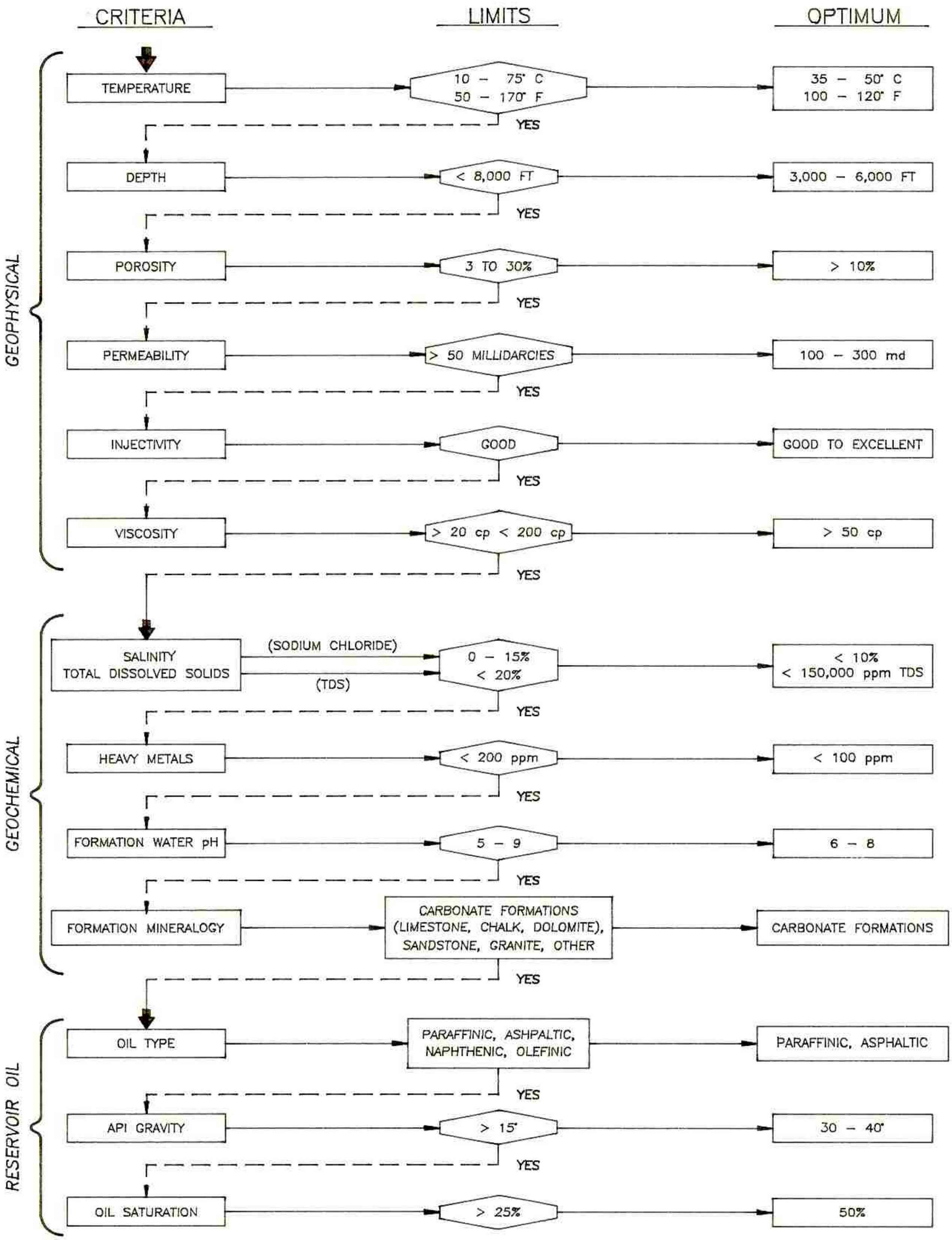
Table 1

A classification of different microbial Reservoir treatments

MEOR process	Production Problem	Type of microorganism used
Microbial well Stimulation	Lack of reservoir pressure Injectivity problems Trapped oil due to capillary forces	Surfactant, gas, acid, and alcohol producers
Microbial well bore Cleanup	Paraffin problem	Micro-organisms that produce emulsifiers, surfactants, and acids
Microbial enhanced water flooding	Trapped oil due to capillary forces	Generally, surfactant, gas, acid, am alcohol producers
Microbial permeability modification	Poor sweep efficiency	Micro-organisms that produce polymer and/or copious amounts of biomass
Microbial polymer flooding	Water bypassing oil Unfavorable mobility ratio	Micro-organisms that produce polymers
Mitigation of coning	High producing water/oil ratio	Micro-organisms that produce polymers and/or copious amounts of biomass

SELECTING MEOR CANDIDATE WELLS



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