

Microbially improved Oil Recovery from carbonate Reservoirs

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Abstract

A treatment for microbial improved oil recovery from fractured-porous carbonate reservoirs by application of molasses and bacteria is presented.

As a result of a screening program we selected clean cultures of the genus Clostridium which are able to grow at the layer of Bashkir from the field Romashkino (Tatarstan) with a temperature at 20°C and poor mineralised formation water (30 g salt/l). In laboratory experiments in which we simulate reservoir conditions, the improvement of oil recovery by imbibition and flooding tests was determined. The recovery of oil with a viscosity of about 65 cP from cores of reservoir beds were after the conventional waterflooding 15 to 17 % and it improved to 29 to 33 % of OOIP by microbially treatment. In the pilotfield we have observed a high content of several bacteria, because it would inject a river water in it over ten years. We aspire to make a dominant fermentation process in the reservoir by means of a special biotechnology. We will give some information about the first results of the injection, which is started in September 1992.

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Much data on microbial metabolism products and the mechanics of their activity have been accumulated since Beckmann 1926 (1) first published information on the possibility to use microbial metabolic processes to improve the oil production rate and since the first field tests were conducted by ZoBell in 1947 (2). These data are regularly discussed at the biennial symposia on Microbial Improved Oil Recovery (MIOR) (3-5). The molasses in situ technology, applied already by ZoBell, remains in the center of interest as well as papers on the oil-desorbing effects and the generation of surfactants, particularly by Bacillus licheniformes (6-9) and on the formation of biopolymers - particularly by Leuconostoc mesenteroides (10, 11) for selective blocking of high-permeability beds. Naturally, no sulfate-reducing bacteria (SRB) are used any longer as MIOR production stock on the contrary. But microbial surfactants production and CO₂- and H₂-formation are supported, as before. Metabolism products of anaerobic fermenting microorganisms, such as alcohols and lower fatty acids, have been added, they are expected to have an improving influence on oil production. Several species and genera of Clostridium and Bacillus are the organisms preferred in MIOR. MIOR technologies are subdivided in (13).

Table 1: History of Microbially Recovery Methods

Cyclic microbial recovery	- injection of bacteria and nutrient solution into a single well, a shut-in and production from the same well (6, 14-20)
Microbial flooding recovery	- method of all-field flooding by injection of nutrient solution and bacteria into one or several wells and production from neighbouring wells (2, 6, 13, 21-28)
Activation of natural microflora	- fieldflooding with nutrient salts and water, containing O ₂ , to multiply hydrocarbon-oxidizing bacteria (21, 29-33)
Selective plugging recovery	- injection of biopolymer-generating bacteria and nutrients to block high-permeability beds, together with flooding technologies (34-37)
Microbial fracturing fluids	- microbial decomposition of long-chain compounds within the formation (38, 39)

Up to now MIOR has been applied mainly in oil deposits with sandstone reservoir rock. More than 300 cases - mostly of single well stimulation - were reported. Based on our own experiments however, we attach great importance to MIOR in fractured-porous carbonate reservoir rock. The potential of carbonate deposits is equivalent to that of sandstone reservoirs, as 50 % of oil reservoirs are found in carbonate reservoir rock. Some of the IOR-technologies, usually applied in sands, such as polymer-, surfactant- and alkaline-flooding show low efficiency in carbonate rock, whereas MIOR, in particular, the anaerobic in-situ fermentation, supported by molasses, is of special interest in carbonate oil deposits. Advantages of carbonate formations in comparison to sandstones are:

- injected bacteria spread wider and more quickly through fissures, fractures and pore canals
- plugging of oil bearing strata by filtration, adsorption and overgrowth of bacteria is minimized
- carbonates neutralize generated organic acids, which intensifies the formation of microbial products
- permeability increases, fresh, not yet drained sections of the reservoir rock are included in the recovery, as a result of the microbial rock solution.

We have conducted fundamental research and developed a ready-to-use technology for application of the molasses-in-situ method in fractured-porous carbonate layer Bashkir of the oil field of Romashkino in Tatarstan.

Characteristics of Bashkirian Reservoir Rock

The reservoir rock is organic limestone of the Carboniferous Mineral content:

calcite	90 - 98%
dolomite	0 - 5%
aragonite	1 - 2%
anhydrite	0 - 1%
pyrite	0 - 1%

Density 2.71 - 2.72 g/m³

The reservoir rock is very inhomogeneous with alternating beds of low (1-3%) and higher (13%) porosity.

The pore radius averages 2.4 - 3.8 μm. A system of microfissures exists. Matrix permeability is 0.1 to 2.0 mD.

Formation characteristics: formation temperature: 20°C
formation pressure: 7 - 8 MPa

Oil properties under formation conditions: heavy oil
viscosity 50 - 60 mPa*s
oil density 878 kg / m³
gas factor 3.2 m³ / t
gas saturation pressure 1.02 MPa
oil volume factor 1.03
molare volume 232

Main components are paraffines, naphthenes, mono-, bi- and polyaromatic hydrocarbons asphalt 13 %, resins 7 %.

Formation water; total mineralisation 30 - 40 g / l

Formation microbiology

Essential prerequisite for the evaluation of MIOR applicability in a certain field is data on the bacterial population in the chosen reservoir rocks. The introduction of nutrients into a deposit will not only support the production culturs injected with the procedure, but also microorganisms, already existent or brought in with the nutrient medium. That must be taken into account, particularly, when using complex nutrient media, such as molasses. In addition, the fermentation of molasses generates metabolic products rich in organic acids, alcohols and hydrogen, available for final anaerobic microbial decomposition. This final decomposition aims either at sulfate reduction or at methane formation. It is influenced by the chemical composition of formation water and reservoir rock (SO₄-ion content), the microbial population of the reservoir and the biological technology. The Bashkirian horizon of the pilotfield Romashkino produces by injection of water as pressure maintenance method. River-water bacteria were not destroyed beforehand, therefore a broad scale of microorganisms; has been brought in with the river-water.

We used 13 complex and special nutrient media for bacteriologic analyses. The content of aerobic, heterotrophic microbes was 1x10⁶ cells / ml. Hydrocarbon-oxidizing bacteria were represented by 10⁴ cells / ml. The content of anaerobic bacteria comes up to 10⁴ cells / ml. River water contained no methanotrophic bacteria. SRB's were represented, mainly by Desulfovibrio, Sporodesulfovibrio and Dessulfofulbo - 10 cells / ml, approximately.

Table 11: Microbial Population in Injection and Production Wells and in reservoir Rock
Average cell content per ml or per g

Physiologic group	Injection Well	Production Well	Core
heterotrophic aerobic bacteria	10^3	10^0	10^2
hydrocarbon-oxidizing bacteria	10^2	10^0	10^3
methylotrophic bacteria	10^3	0	10^2
thiobacteria	10^0	0	10^2
heterotrophic anaerobic bacteria	10^4	10^1	10^1
fermentation bacteria	10^5	10^0	10^3
SRB's	10^5	10^2	10^2
methanogenic bacteria	10^0	10^0	10^1

Table 11 presents the average cell contents of freshly recovered samples. Note the rich population in injection wells. It is caused by continuous introduction of bacteria into the formation and by improved development condition for near-well microorganisms. At the end of the flooding periods hydrocarbon-oxidizing bacteria predominate, due to oxygen supply with die river water. During the noninjection periods oxygen is exhausted within the formation. Under anaerobic conditions SRB's develop on biomass and organic acids, generated by hydrocarbon-oxidizing bacteria. SRB's are the dominant physiologic group near production wells, together with some heterotrophic anaerobic and methanogenic bacteria. Bacteriological analysis of drilling dust taken under sterile conditions from cores of the Bashkirian horizon, show a considerably richer bacterial population of the reservoir and a broader scale of species than fluid samples, which included only 1 to 10 %, approximately bacteria in place. This is due to overgrowth of bacteria and filtration in the pore space, as repeated examinations have shown.

Using a molasses-in-situ technology the scientist has to take into consideration, in particular, the existing formation of microflora. Previous analysis confirmed that die introduction of energy-rich compounds, such as sugar, and improved nitrogen- and phosphate-availability increase the cell content of innate microflora to 10^9 to 10^{10} cells /ml within two to four days. Various Cocci, Streptococci, Lactobacteria, Pseudomonas and Alcaligenes, in particular, produce large quantities of organic acids by short decomposition times, as well as simple polysaccharides (dextranes, mucosanes), which quickly alter the ecologic conditions in the well-near zone to an extent, subduing the MIOR-relevant product synthesis, by injected Clostridia for instance. In these cases we have to provide special microbiologic and technological preconditions to insure a directed, dominating fermentation process by:

- selection of Clostridia with high metabolic efficiency
- synthesis of metabolic products with bacteriostatic effects especially on SRB's
- analysis of ecologic reservoir characteristics and optimization of growth conditions for Clostridia
- development of a technology, providing the cultivation of Imp volumes of inoculum at the site
- massive starting inoculation of the reservoir with bacteria, being in die logarithmic stage of growth.

Selection of Clostridia

In accordance with the ecological conditions in the layer Bashkir we selected appropriate bacteria for the following conditions:

temperature	15 – 30°C	synthetic formation water:	
total mineralisation	10 - 50 g /l	NaCl	13.84 g/l
pH	5.0-7.5	KCl	10.00 g/l
pressure	0.0 - 10 MPa	NaHCO ₃	1.6 g/l
solute oxygen	0.0 - 10 mg/l	CaCl ₂	3.36 g/l
redox potential	-400 - +150 mV	MgCl ₂ *7H ₂ O	5.76 g/l
		Na ₂ SO ₄ *10H ₂ O	16.78 g/l

The isolation was conducted in liquid media based on synthetic formation water. The nutrient was made by adding molasses 20 to 80; KH₂PO₄ 0-01 - 0.25; NH₄Cl 0.1 - 0.5; ascorbic acid 0.1 g/l. The addition of CaCO₃ was to neutralise generated organic acids. The starting pH was approximately 7.5. In practice a tolerance of oxygen was desirable, therefore isolation was conducted in high layer in presence of oxygen of the air and biogas. The starting redox-potential amounted to -40 and +90 mV. Within a screening program we isolated Clostridia from different material, in particular, from compost soil formation and reservoir water. Strains of the species Clostridium thyrobutyricum proved to be suited. Their remarkable feature is intensive gas production mounting to 330-370 ml gas per gram introduced molasses, high generation of alcohols and biosurfactants. This species is mobile has a low tendency of spore formation and generation of relatively small cells of 1.5-1.2 µm in the product formation phase.

Interaction of Clostridium thyrobutyricum spec. and Reservoir Microflora

The molasses fermentation generates energy-rich metabolic products, which may react in the final decomposition line of methanogenesis or sulfate reduction under anaerobic formation conditions. With sulfate-ion in the formation water sulfate reduction predominates. The H₂S produced is not desirable. It causes well-blocking by precipitation of iron sulfide together with mucous development, considerably reduces the quality of recovered oil and gas, increases corrosion of well installation and surface equipment and by its toxicity pollutes the environment.

The formation water of the Bashkir contains 1 g/l sulfate, approximately, SRB's had been identified in all wells. Therefore investigations on the interaction of CL. thyrobutyricum and SRB's were, necessary.

Tests were run - with nutrient medium with 4% of molasses in innate sulfate bearing Bashkirian formation water
- oil culture from the reservoir, including Vibrio desulfuricans, Desulfovibrio desulfuricans, Desulfohalobium, Sporodesulfovibrio, and a pure culture of CL. thyrobutyricum, strain K3

Medium (a) included a pure culture of Clostridia, medium (b) a mixed culture of Clostridia and SRB's, medium (c) only SRB's. Figure 1 shows that the culture of Clostridia (a) develops normally, With 3 hours of generation time maximum content of 4x10⁹ cells /ml was reached after 12 hours. The gas production rate reflects the degree of metabolic activity. With strain K3 it is 320 ml/g molasses. Mixed culture (b) was inoculated with a thousandfold content of SRB's compared to dust of the reservoir. The presence of a high starting content of active SRB's did not considerably influence the cultivation and metabolic efficiency of Clostridia.

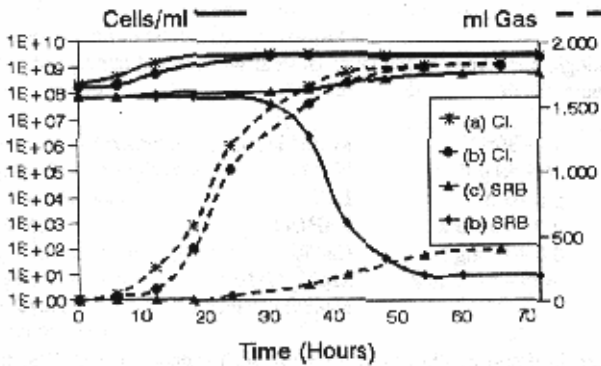


Figure 1 - Growth and production of gas in a mixed culture Clostridium thyrobutyricum and SRB's

It is very interesting the SRB's were suppressed by the metabolic products of Clostridiae. Unexpectedly, we observed not only a bactivsiostatic inhibition but a destruction of SRB's, reducing the content of cells to 10 per ml at the third day. In accordance with SRB's development H₂S was detected only in medium (c).

Figure 2 shows that die growth inhibition or destruction of SRB's depends on the concentration of metabolic products, generated by Clostridiae. A test was made with Cl. thyrobutyricum N50 in presence of granulated limestone and Bashkirian formation water with molasses concentration of 2 and 6 % used SRB's with a starting content of 10²; 10⁴ and 10⁶ cells/ml. With molasses concentration of more than 2 % the concentration of bactericidal substances increases to a degree, which is destructive to vegetative SRB's cells. The remaining (10 cells/ml , approximately), is due to SRB's spores, when large inoculation volumes were used.

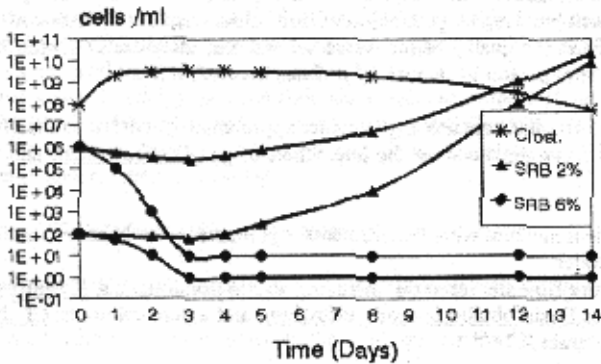


Figure 2 - Growth of a mixed culture from Clostridiae and SRB's by various concentration of molasses

The SRB's-inhibition effect of a molasses solution, fermented by stains of Clostndiac, was investigated with bactericidal tests. Fermented nutrient solution was mixed with formation water, using concentrations of 0 to 96 %. 0.1 % of ammonium ferrous sulfate was added to the formulation, as well as NaOH to adjust the pH-value to 7.2. After that the SRB's of the Romashkino

field were inoculated to give a starting content of 10^2 cells per ml. After an influence period of 1, 3, 7, 14 days and 4 weeks the live cell content was ascertained by the MPN-method in a SRB's-medium. As shown in figure 3, SRB's were destroyed in formulations with low dilution of the fermented nutrient solution. Beginning from a dilution of 1:1, only a slight multiplication to 10^3 cells/ml starts. An inhibition of SRB's is to be observed up to a dilution of 1:5. Maximum SRB's cell content occurs with a dilution of fermented nutrient solution of 1:10. With higher dilution the nutrients in the medium were not sufficient to initiate intensive metabolic processes. The results of die bacteriological investigations were confirmed by the H_2S -content of the medium.

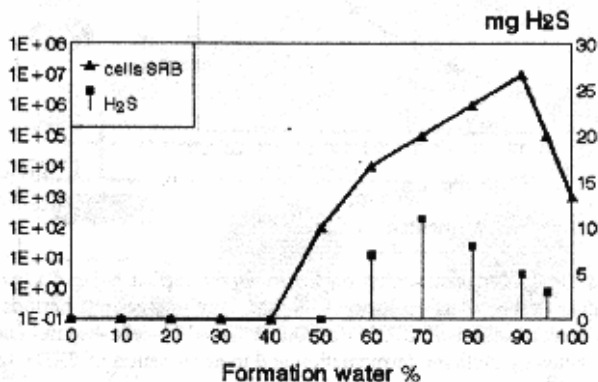


Figure 3 - Bacteriostatic, effect of fermented nutrient solution on SRB's

The metabolic products of some strains of *Cl. thYRObutyricum* have a bactericidal effect, especially on SRB's. According to present results they do not inhibit other physiologic groups of bacteria. Therefore it may be possible to direct the final decomposition of hydrogen, organic acids and alcohols towards methane generation, even in presence of sulfates in formation waters.

Mixed cultures of methanogenic bacteria, including *Methanobacterium*, *Methanococcus* and *Medianosarcina* were inoculated into 300 ml of fermented 6-% molasses nutrient solution to give a starting content of 1×10^4 cells/ml. In a parallel test 300 ml of fermented nutrient solution were mixed with 300 ml of formation water (figure 4). In contrast to SRB's, methanogenic bacteria were not destroyed, even in an undiluted medium. The cell content increases to 10^8 cells/ml within 10 days. The gas production equalled 120 ml/g introduced molasses (as liquid fermentation products) in both tests. The biogas contained 77 % methane. In other test series biogas as well as nutrient solution, fermented by Clostridiae, were inoculated with mixed culturcis of methanogenic bacteria and SRB's. The test used 500 ml of sulfate-containing nutrient solution with 31g of introduced molasses and 80 cm³ of rock powder from cores of the Bashkir. In the first stage the molasses was fermented by *Clostridium thYRObutyricum*. 9,700 ml biogas -CO₂ and H₂ -, generated in this phase, were collected. The fermented nutrient was inoculated with 15 ml of methanogenic and 15 ml of sulfate-reducing bacteria (5×10^9 cells/ml). Just as with the test described above, the cell content of SRB's decreased through the first three days, whereas the methanogenic bacteria increased to 4×10^9 cells/ml After 50 days a bacterial film had developed at the interphase to the biogas.

Figure 5 illustrates the volumetric changes of the gas components CO₂, H₂ and CH₄ through the test period. During the first days, in particular, a large volume (54 %) of methane was generated by CO₂ and H₂, whereas later 80 to 90 % of methane came from organic acids and alcohols.

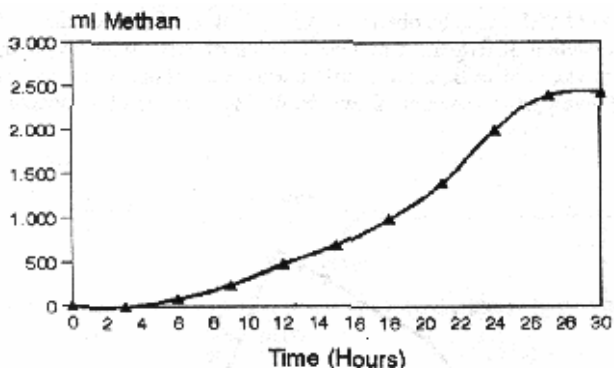


Figure 4 - Production of Methane from fermented nutrient solution

Within the first 60 days the CO₂ : H₂ consumption ratio was nearly perfect being 4 l hydrogen per l CO₂. H₂S did not appear during a testing period of 80 days. With longer test periods traces of H₂S were observed. A multiplication of SRB's to contents of 10⁴ cells began, due to a decrease of biocidal components by methane fermentation and to germination of SRB's spores.

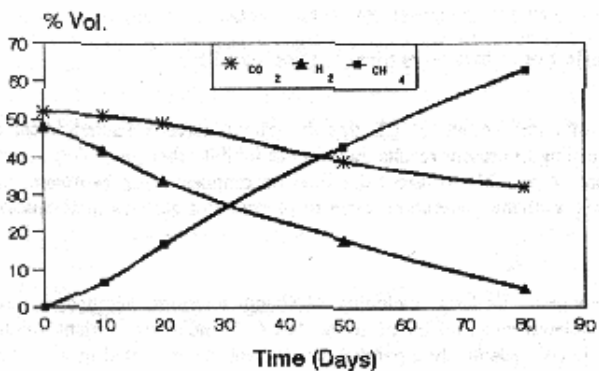


Figure 5 - Change of the Composition of Biogas in a mixed culture from methanogenic and sulfate reducing Bacteria

Inoculum Cultivation at the Site

A massive start-inoculation of the injection medium is necessary to provide a domination of the fermentation processes by Clostridia in a well or a reservoir with innate bacteria. Lab tests with rich-germ material (10⁶ contaminants/ml) and long-period tests, using rock material and repeated injections have shown that a reliable process development calls for an active inoculation medium with an inoculant / injection medium ratio of 1 : 10 up to 1 : 20 over the total injection period. Therefore biotechnology has to be integrated in MIOR-technologies far more than practised up to now, when high-volume injection of several thousands of cubic meters into single wells or all-field flooding is required.

We designed surface fermentation plants for our field tests, adapted to the technological scheme of mass cultivation of Clostridia. Figure 6 shows the general construction of the plant. It is mounted on two sledges and housed in containers. Container No. 1 includes all appliance for medium production, as the nutrient salt tank, media tanks, pumps etc., container No. 2 – vaporizers for plant sterilisation, the inoculation fermenter, a 2.5 m³ - cultivation fermenter, the mixing line for preparation of the injection medium and the injection pump. The plant is automatically controlled by principle of continuous cultivation by Clostridia activity in the main fermenter.

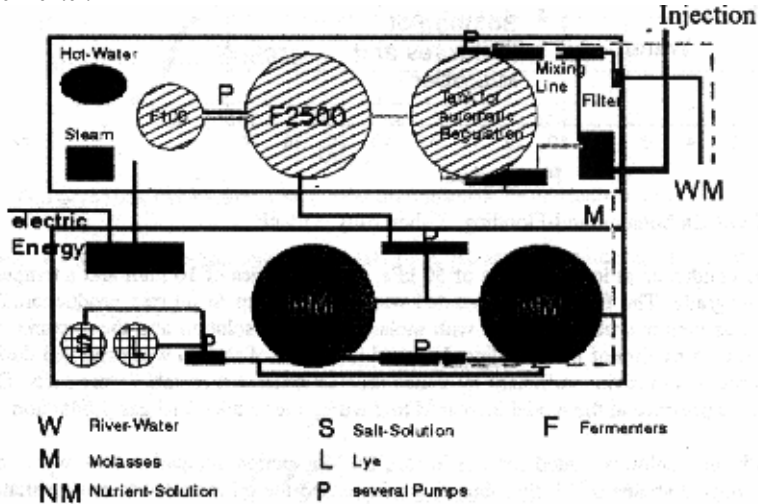


Figure 6 - Plant for Fermentation and Injection

In correspondence with the Clostridia-generation time of approximately 4 hours we produced up to 10 m³ 1 day pure cultures, which is sufficient for an injection volume of 100 to 200 m³/day. We prefer a batchwise starting inoculation with 1 to 3 m³. The pilot test in the Romashkino oil field uses this type of plant which guarantees a planned injection volume of 3000 m³ per well and test period. The first results of this pilot test will be presented at the IOR session in Moscow in 1993.

Lab Results of Oil Drainage Tests

Simulation costs had to prove the applicability of the molasses in-situ technology to an individual reservoir. A technology is suited, when the injection of selected production strain and molasses media initiates a fermentation process in the reservoir rock which generates metabolic products and thereby increases oil recovery after water flooding to an extent which considerably exceeds results, gained by the traditional flooding method.

In preliminary tests we used granular models, containing limestone in order to select the most active microorganisms for additional oil recovery. The thermostatic flooding apparatuses included steel test vessels (140 mm long Ø 43 mm), filled with rock material. The rock mixtures with grain sizes of 0.1 to 1.0 mm provided permeabilities of 150 to 200 mD. The package porosity was 33 %. The granulate was saturated by oil from the reservoir (viscosity 65 cP).

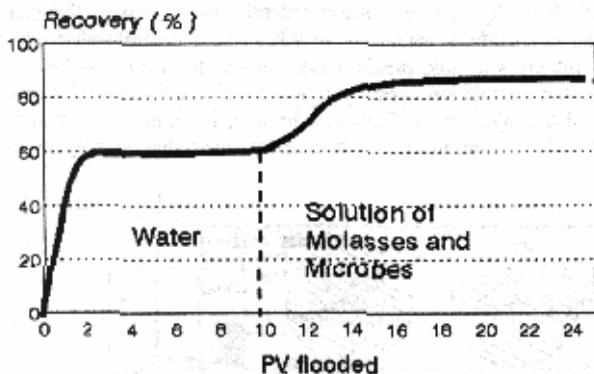


Figure 7 - MIOR Carbonate-Sand-Flooding, Oil viscosity = 65 cP

The tests were conducted at low pressures of 50 kPa, flow velocities of 10 ml/h and a temperature of 20°C. The first phase simulated water flooding up to oil-free production. The rock material was then microbially treated with molasses nutrient solution and the bacteria, selected for the test. A rhythm of three flooding days and four days of shut-in was observed during the flooding process to provide sufficient influence time of generated metabolic products. During this stage the pressure in the model increased to 2 Mpa, due to microbial gas production.

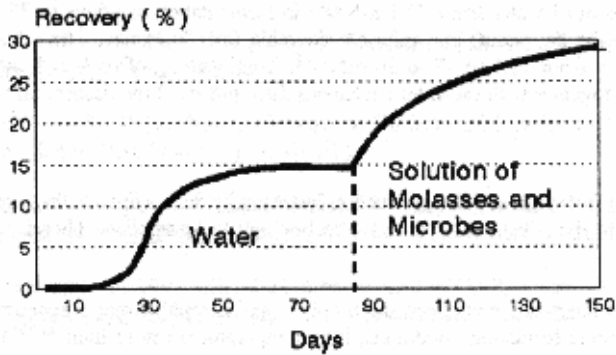
To select production cultures, suited for a field test, 30 long-period simulation tests were conducted. Well adapted strains of *Cl. thuyobutyricum* increased the oil recovery to approximately 30 % after an oil drainage by water flooding of approximately 55 % (fig. 7). An average of 70 % of the oil, remaining in the model after water-flooding, was additionally recovered.

The most active strains of bacteria, selected by means of granular models, were tested in imbibition and core models under formation pressure. Simulation tests with original cores, based on the principal of ring-fracture-flooding tests, resulted in a drainage of 15 %. This approaches the maximum oil recovery of 17.5 %, calculated for this field. During the microbial treatment oil drainage was improved to 28.9 % (fig. 8).

With imbibition tests we used core sections of approximately 50 g. They were extracted, dried, evacuated in pressure chambers and oil-saturated under a pressure of 8 MPa. Afterwards they were stored in formation water for 50 days. The volume of released oil was measured by liquid exchange without formation pressure change. Approximately 5 to 10 % of the initial oil volume was drained. After treatment with molasses nutrient and *Cl. thuyobutyricum* we observed a considerable increase of recovered oil, already after four days. This intensive drainage continued 15 days followed by a long period of low drainage. 70 Days after starting the microbial treatment 40 to 59 % of the initial oil was recovered, see figure 9.

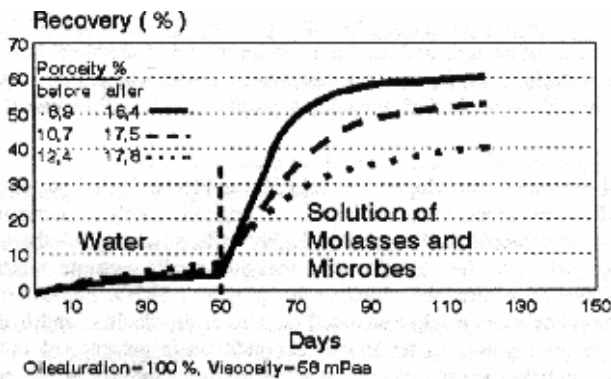
The oil recovery increased because of the low efficiency of the preceding water-flooding method with:

- increasing oil viscosity
- decreasing porosity of the reservoir rock
- change front hydrophobic to hydrophilic rock



Porosity=10 %, Oil saturation=79 %, Viscosity=58 mPa.s, PV flooded= 0,25/d

Figure 8 - MIOR Core-Flooding; Carbonate rock, Reservoir conditions, Fractured-Simulation



Oil saturation=100 %, Viscosity=58 mPa.s

Figure 9 - MIOR Imbibition-Tests; Carbonate rock, Reservoir conditions

In pressure chambers we observed a pressure rise of 8 to 11 MPa, caused by the generation of the biogases CO_2 and H_2 . It is to be supposed that the total pressure rise within the model is accompanied by changes of the pressure potential in the matrix, due to in-situ gas generation in pores and fissures. This creates an energy potential which contributes to oil migration in the reservoir. Further more, the solution of gas and consequently, the change of the oil volume factor lowers the oil viscosity and improves the rheological properties, as already known with CO_2 flooding.

Organic acids, such as acetic, propionic, n-and iso-butyric acid, are generated during the fermentation process. The pH decreases to 4.8. Mass determination and analysis of Ca^{++} - and Mg^{++} -ions in the surrounding medium confirmed that approximately 0.2 t of rock per ton of molasses were dissolved. This considerably improved porosity (from 8.9 to 16.4 %). The enlargement and expansion of migration path, as well as the inclusion of fresh matrix system, due to rock dissolution in fissures and pore canals, is one of the fundamentals of the high efficiency of this technology in carbonate reservoir rock.

Clostridium thyrobutyricum generates methanol, ethanol, propanol, butanol and sometimes isoamyl alcohol. The bactericidal effect on SRB's is attributed to the alcohols, in particular, to

propanol. Alcohols, lower fatty acids and biolipides which are released with autolysis of the cells lower interfacial tension of water from $72.1 \text{ mN}\cdot\text{s}^{-1}$ in fermentation solutions to 37 to $44 \text{ mN}\cdot\text{s}^{-1}$ which is specific for the strain, but quite considerable for Clostridiae. The interfacial tension to heptane dropped from 46.5 to 12 to $20 \text{ mN}\cdot\text{s}^{-1}$. Total wetting of rock and capillary adsorption of the nutrient together with oil/water exchanges thus improved the desorption of oil.

Summary

Ecologic factors of oil-bearing strata and the production history of a field influence the direction of microorganism selection for MIOR as well as the technology to be applied. Therefore it is essential

- to isolate and/or adapt to formation conditions thermophilic and halophilic microorganisms for use in reservoirs with extreme formation conditions, high temperatures (more than 50°C) and high salinity values (more than 70 g salt/l).
- to create conditions for microbial activity by introduction of inhibitors, by dilution of the formation water and injection of adapted microorganisms in formations, previously treated with bactericides during secondary and tertiary methods of oil recovery.
- to select highly efficient strains of bacteria and use the most appropriate technology in order to provide domination of the biotechnological process in reservoirs with autochthonous microflora or with microbes brought in with technological procedures (drilling mud, well treatment, flooding).

As a result of fundamental research we developed the biological and technological principles for a pilot test of field-wide MIOR in carbonate reservoirs, bacteriologically highly contaminated by previous water flooding without biocides. We selected highly efficient strains of the species Clostridium thuyobutyricum, which by fermentation of a molasses media generate substances, either destructing, or - in lower concentrations inhibiting the growth of SRB's. Because of that; the final microbial decomposition of primarily generated organic acids, alcohols and hydrogen can be directed to a methanogenesis even under anaerobic conditions in presence of sulfate in formation waters. The exceptional efficiency of the molasses-in-situ-technology in oil drainage of fissured-porous carbonate reservoir rock was confirmed by simulation. It is due to the rock-dissolving properties of organic acids, generated by bacteria the improvement of migration paths and the inclusion of fresh undrained sections of the matrix in the fissure system.

The neutralisation of organic acids at the reservoir rock facilitates the use of high molasses concentration and thereby the production of great volumes of active substances in the reservoir.

The main factors, increasing oil desorption from the reservoir rock are:

- improvement of capillary absorption of flooding media into the matrix
- exchange processes between the nutrient media and the oil in the pore space
- change of pressure potential and introduction of energy in the formation
- decrease the oil viscosity.

The application of MIOR in microbially contaminated formations requires continuous or, preferably, batchwise inoculation of the injection medium with cultivation strain of high cell content, being in the logarithmic stage of multiplication. This calls for modern biologic technologies to cultivate large volumes of inoculum in sterile fermentation plants at the production site.

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