Reservoir Engineering Review of an Microbial Enhanced Oil Recovery Process in a North German Petroleum Reservoir

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Abstract

While screening processes to enhance oil recovery from petroleum reservoirs in North Germany also Microbial Enhanced Oil Recovery (MEOR) was considered.

An organism of the strain *pseudomonas stutzeri* was isolated from the residue of an oil/water separator. This organism was capable to produce nitrogen and carbon dioxide using glucose as substrate and nitrate. The isolation procedure, the growth conditions and the gas producing rates are discussed in the paper. The influence of salinity, temperature and the competition with sulphate reducing bacteria, present in the reservoir, were investigated under anaerobic conditions..

The applicability of the MEOR-process in a huff and puff stimulation was studied for the Lehrte oil field. Model calculations were made, the influence of solubility and diffusion of the CO_2, produced by the bacteria, in the oil were investigated, as well as pressure development in the reservoir and the region around a well bore. Pressure increase due to gas production by the bacteria was related to the amount of nutrient, that had to be injected.

The investigations show, that, from a reservoir engineering point of view, the efficiency of the process has to be regarded as poor.

1 Introduction

A survey of the literature with reference to MEOR field-projects showed that the effect of bacterial activity in the reservoir is often overestimated. The slight incresases in oil production, which were observed in many cases, can be attributed to a stimulating effect by bacterial metabolism products. Mainly bacterial cultures isolated from the reservoir water or bacteria of other origin, which were adapted in the laboratory for reservoir conditions were used. The application of the MEOR process was carried out in selected wells, which for the most part were not in employed due to production problems.

As part of this study, the feasibility of a Huff and Puff process with gas-produced by bacteria was examined in a selected reservoir. In part of the Lehrte reservoir is a lack of flow in the wells/reservoir due to the precipitation of oil colloids. In the south section of the Lehrte reservoir there is insufficient communication with the aquifer. This is why the reservoir pressure fell. The high water cut led to production shut-down in many wells.

Therefore besides other EOR-methods microbial enhanced oil recovery was also considered as a process to improve recovery from this field.

2 The MEOR process

In order to understand the MEOR process, it is necessary to look at the metabolism and the growth relationship of the bacteria. A general analysis of the factors influencing growth revealed, that bacteria could survive under extreme reservoir conditions. Taking into consideration the reservoir outlined above, there are only a few possibilities of altering the salinity and temperature of the reservoir in favour of improved living conditions for bacteria.

An important element of the MEOR process is the metabolism performance of the bacteria. An facultative aerobic organism from the strain *pseudomonas stutzeri* (rodlike; length: 1.4-2.8 μm; diameter: 0.75-0.85 μm) which had been isolated in the production plant from bottom residues of the oil water separator was analysed in terms of generation time and gas production by denitrification of glucose in the laboratory. The optimal living conditions of the bacterium strain are given in Table 1.

Table 1: Optimum living conditions of pseudomonas stutzeri

Salinity range	20 - 80	g NaCl/L
Temperature (max.)	41	°C
pH-value (opt)	6.8	

Under laboratory conditions, *pseudomonas stutzeri* is capable of producing CO_2 by utilising glucose and N_2 by utilising nitrate as an electron acceptor.

Table 2. Theoretical gas production and results from laboratory tests

1 kg Glucose (2.24 kg KNO_3) yield:	theoretical	laboratory	
CO_2	0.747	0.313	m^3
N_2	0.249	0.227*	m^3

*the formation of different N/O-components during the fermentation is considered in the calculation

The following criteria led to the selection of *pseudomonas stutzeri* for the application in a MEOR process:

- The *pseudomonas stutzeri* originates from the area surrounding a reservoir

- Denitrification is the most effective gas production process of bacteria.

- The *pseudomonas stutzeri* usually do not compete with sulphate-reducing bacteria, as they cannot tolerate the presence of nitrate.

During injection of the growth solution, it is possible by appropriate means to slow down the development of the bacteria; e.g. by using bacteria cultures which are at the early stage of growth. It is important to keep the concentration of cell bodies low during the injection, because the adsorption of the bacteria in the reservoir and the bridging due to the high concentrations can lead to a significant reduction in the permeability. This can cause problems during growth solution injection.

3 Reservoir description

The essential reservoir parameters with respect to MEOR are given in Table 3.

Table 3: Reservoir parameters of the Lehrte oil field

Formation	Sandstone	
Depth	1090	m
Thickness	0-30	m
Temperature	48	°C
Pressure, initial	123	bar
Pressure, actual	60	bar
Water saturation, initial	25	%
Water saturation, actual	35	%
Salinity	160	g/L
Oil viscosity	3.5	mPas
Porosity	18.2	%
Permeability	240	mD

The reservoir rock is a Jurassic sandstone conglomerate (Cornbrash), which contains significant amounts of carbonate cement. The reservoir is a dual porosity system with fissures. The poor oil recovery of 14 % of the original oil in place only is mainly explained by this fact.

3. Stimulation process

3.1 Bacterial growth rate and gas production

Using a model well, the most important elements in a stimulation procedure were analysed. As the bacteria cells are destroyed due to excessive pressure tension in the perforations around the well bore, there exists an upper limit for the injection rate of the growth solution. The maximum injection rate for the particular permeability chosen in this example was calculated to be 3.55 m^3/h. It was assumed, that 282 m^3 of inocculum were injected. The total injection time would then result in 80 h. In Fig.1 the theoretical growth curve for *pseudomonas stutzeri* is shown. It is obvious, that already during the injection phase the bacteria start growing and producing gas.

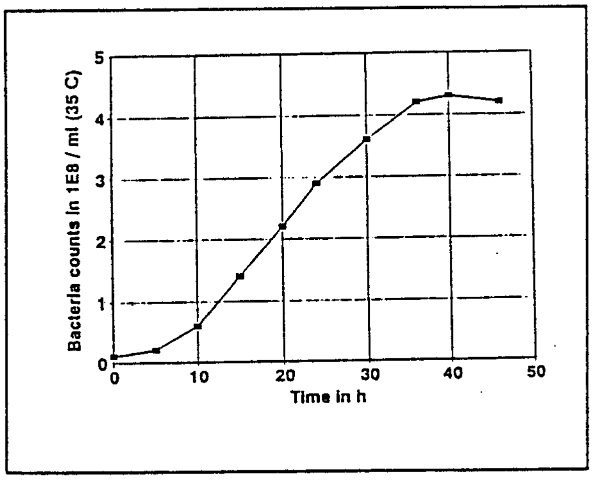

Fig. 1: Growth curve of pseudomonas stutzeri

The gas production by the bacteria was calculated. The result is shown in Fig.2.

The maximum possible gas production was found on the basis of laboratory experiments on *pseudomonas stutzeri*. The amount of gas produced from a particular volume of growth solution is limited because bacteria cannot survive at a high glucose concentration.

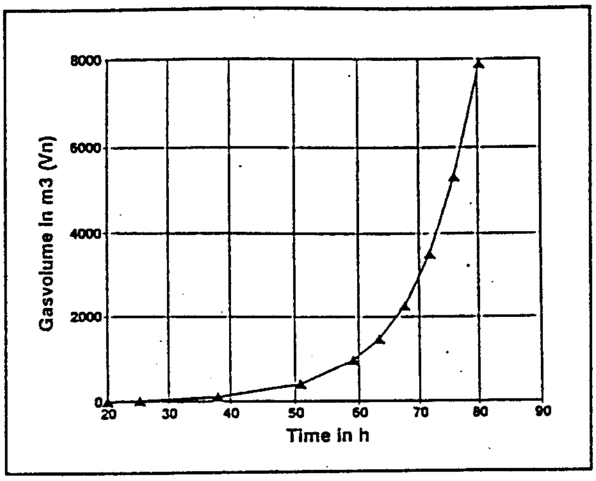

Fig. 2: Cumulative gas production vs. time

3.2 Pressure response

In Fig.3 the pressure distribution around the well bore is shown at different times after the injection of the growth medium. According to the viscosity of the liquid, which was 1.05 mPas, the pressure increase above the initial reservoir pressure was 30 bar (3000 kPa) immediately after the injection of the growth medium. Already 3 h after stop of the injection the pressure distribution around the well was constant and the pressure level decreased to 7 bar (700 kPa) and 3 bar (300 kPa) after 24 h.

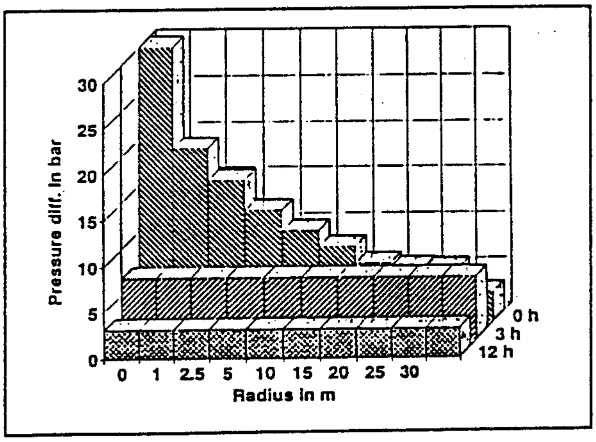

Fig. 3: Pressure distribution in the reservoir after the injection of the growth medium as a function of time and distance from the injection well.

The pressure increase in the reservoir resulting from the gas production was calculated using the flow equation for compressible media. The pressure increase was calculated using a simulated injection of the gases produced. In order to take into account the dependence of gas production on time, the gas was injected at various rates. The calculations yielded a pressure increase at the bore hole wall of 2.25 bar. The development of the pressure distribution is shown in Fig.4.

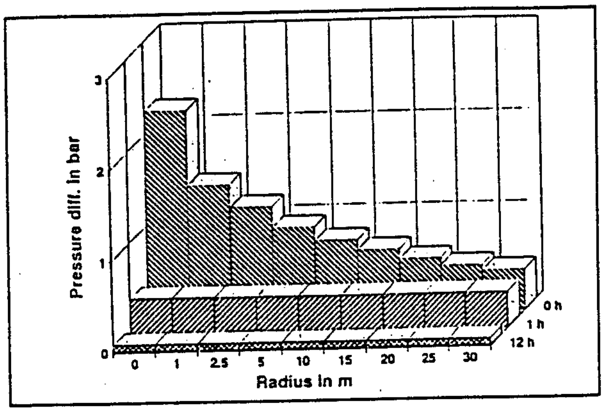

Fig. 4: Pressure distribution in the reservoir after the injection of gas as a function of time and distance from the injection well.

While analysing the time-dependent values, it should be borne in mind, that the pressure decreases in a 12 hour period to a meaningless value of 0.1 bar. The pressure increase resulting from the gas production is a process which is mathematically very difficult to be described. In the study, which was performed, the only possibility of calculating the pressure relationship in the reservoir was from analytical solution of the flow equations.

A comparison of the pressure relationship in the reservoir during the injection of growth solution and the production of gas shows, that the injection of the growth solution introduces significantly more energy into the reservoir than the production of gas by the bacteria.

3.3 Oil production

The physical properties of oil are influenced positively through the dissolving of carbon dioxide. The gas produced by the bacteria is at first dissolved in the water phase. Solubility calculations show, that the amount of gas produced overrides the saturation concentration of the reservoir water. Taking into consideration the distribution coefficients, the gas also is dissolved in the residual oil phase and does not develop a free gas phase. But the concentration of the gases in the residual oil is not sufficient in order to cause a recognisable increase in volume or a decrease in viscosity and a consequential mobilisation of residual oil. According to literature data as a rule of thumb about 2-3 t CO_2 are needed to produce 1 m^3 of incremental oil. This would mean that in the case discussed here about 3 m^3 additional oil can be produced from 282 m^3 growth media, which contains 14 t glucose and 31 t KNO_3.

In conjunction with diffusion calculations, it was clarified what influence the diffusion has on the huff and puff process. In one model, which allows for the analysis of diffusion in the microscopic area of the reservoir, the mass transport was calculated from a saturated water phase into a water zone with an infinite expansion as well as into a never ending oil phase. The results show that a noteworthy balance in concentration can only be expected after 1000 days. Therefore, the diffusion process has no effect on the volumetric recovery rate of the reservoir. A second model represents a CO_2 saturated water phase in a pore area with residual oil saturation. The oil drop representing the residual oil is almost completely saturated within a very short time in carbon dioxide.

The dominant recovery mechanism is solution gas drive. This will decline rather rapidly, because the reservoir liquids are only saturated with gas to a particular level. This is why it can be assumed that mainly the injected growth solution will be produced back.

4. Conclusions

Different MEOR processes were analysed and as a suitable process a huff and puff stimulation was chosen for a particular reservoir.

An organism from the strain *pseudomonas stutzeri*, which had been isolated from an oil/water separator, was analysed in terms of bacterial growth rate and gas production potential.

The stimulation process was modelled for an existing oil reservoir. it was found that the pressure increase caused by gas production of the bacteria is only marginal.

From a reservoir engineering point of view incremental oil recovery from such a process can therefore be regarded as poor and uneconomical.

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