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XANTHAN-BIOPOLYMER FLOODING IN A NORTH-GERMAN OILFIELD

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Summary

The oilfield Eddesse-Nord is located in North-Germany and produces from many blocks of Wealden and Valangian sandstones since 1950. Reservoir depth is 200-400 m, temperature is 22 °C and the salinity of the reservoir brine varies from 30 to 120 g/l TDS.

A polymer screening was carried out, and a Xanthanpolysaccharide was selected for a polymer pilot project. Parallel to polymer screening a suitable block in the field was chosen for the pilot project. A well was drilled and cored through the entire pay zone to obtain sufficient and representative rock material for further laboratory studies.

A reservoir simulation study was performed on the pilot block of the reservoir, using an in house developed reservoir simulation model with polymer option. After intensive and successful history matching, prediction runs were carried out to evaluate the performance of a polymer flood. Also the design of the polymer flood, i.e. slug sizes, injection pattern, injection rates and polymer concentration, was done by simulation.

Injection facilities for the preparation of the polymer solution were designed tested and installed in the field.

The injection of a water preslug started in September 1984. A secondary gas cap, which had developed during primary production, was displaced by water injection, and additional data for an improved adjustment of the simulation model were obtained.

Polymer injection started in October 1985. No injectivity problems occured during polymer injection. It is planned to inject a slug of about 30 - 40 percent hydrocarbon pore volume until March 1988. A response in the first well was observed in December 1986.

1. Introduction

For the majority of the oilfields in North Germany the most promising EOR-method besides steam flooding in some heavy oil reservoirs is chemical flooding. CO_2-flooding is not feasible because there is not enough CO_2 available under economic conditions.

So research was focussed on surfactant and polymer flooding. The polymer field pilot project that will be presented in this paper is part of a research programme on chemical flooding that was carried out by Bayer AG and PREUSSAG AG and supported by the Ministry of Research and Technology of the FRG, and supervised by Jülich Nuclear Research Centre.

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2. Reservoir description

2.1 Reservoir properties

The Eddesse-Nord oilfield is located in northwest Germany between the cities of Hannover and Braunschweig. It was discovered in 1950 at the northern flank of a salt dome. Oil production comes from three separated main parts of the field.

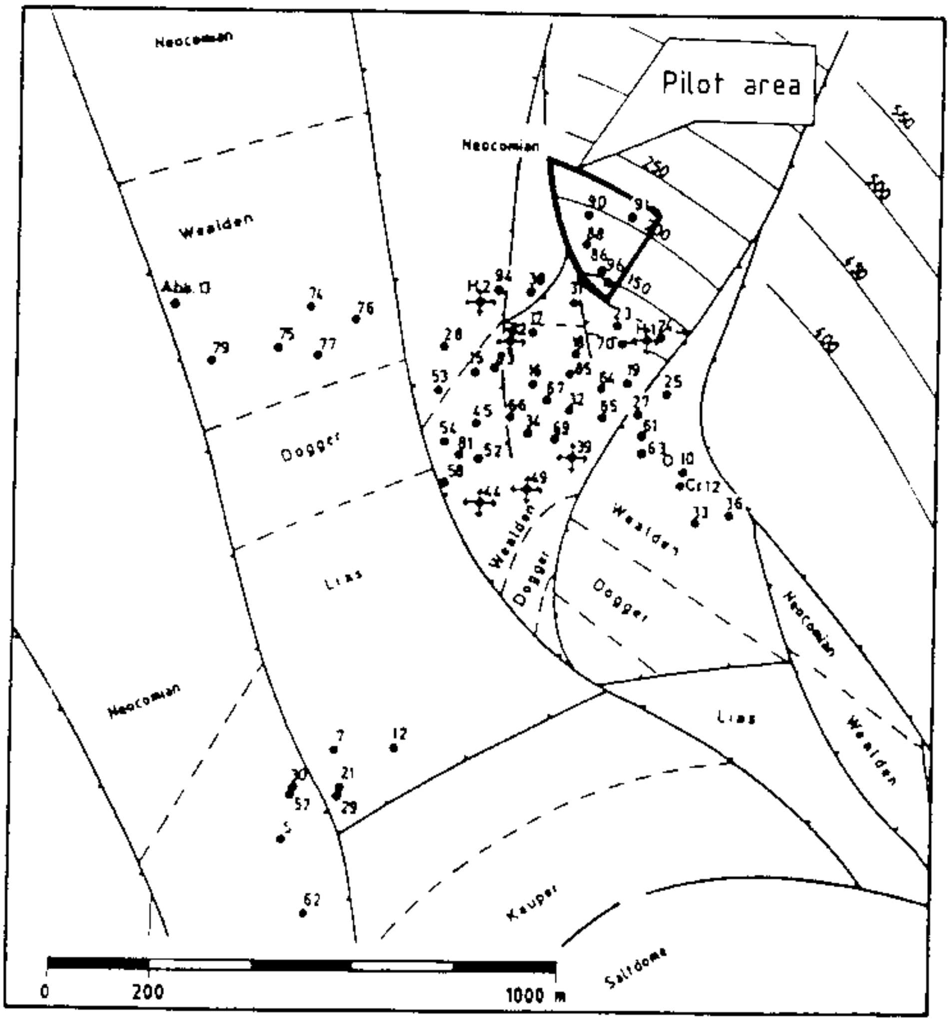

Fig. 1 Structure map of the oilfield Eddesse-Nord

Pay zones are Valangian and Wealden sandstones in the northern parts of the field and Liassic and Rhaetian sandstones in the south. Initial oil in place was 1.68 · 10^6 t. Cumulative oil production in 1984 was 757,000 t, the average water cut 88 %.

Since 1950 80 wells have been drilled in the field, 41 wells are still producing. Gas was injected for a short period into the up dip wells 44, 49 and 39, but water flooding is the main recovery method in the field. Water is being injected into the wells H1, H2, 82 and 91. Using these secondary recovery methods about 50 % of the oil in place could be recovered, another 10% are estimated to be recoverable by chemical flooding.

2.2 Selection of a Pilot Area

Block 5 in the northern part of the field was selected for a pilot project. In this block 6 sands G, I, M, Q, U and W are oil saturated. The overlying Valangian sandstone and the Wealden sand A, C and E are water saturated. A representative log is shown in fig. 2, and a structure map of the block is given in fig. 3.

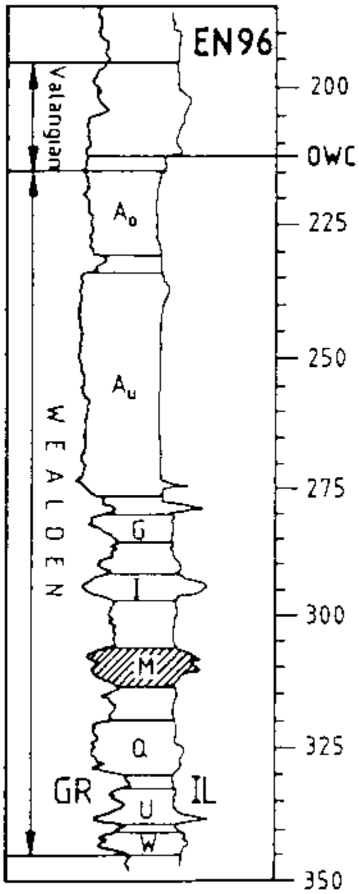

Fig. 2 Electric log of well 96. Polymer pilot in layer M

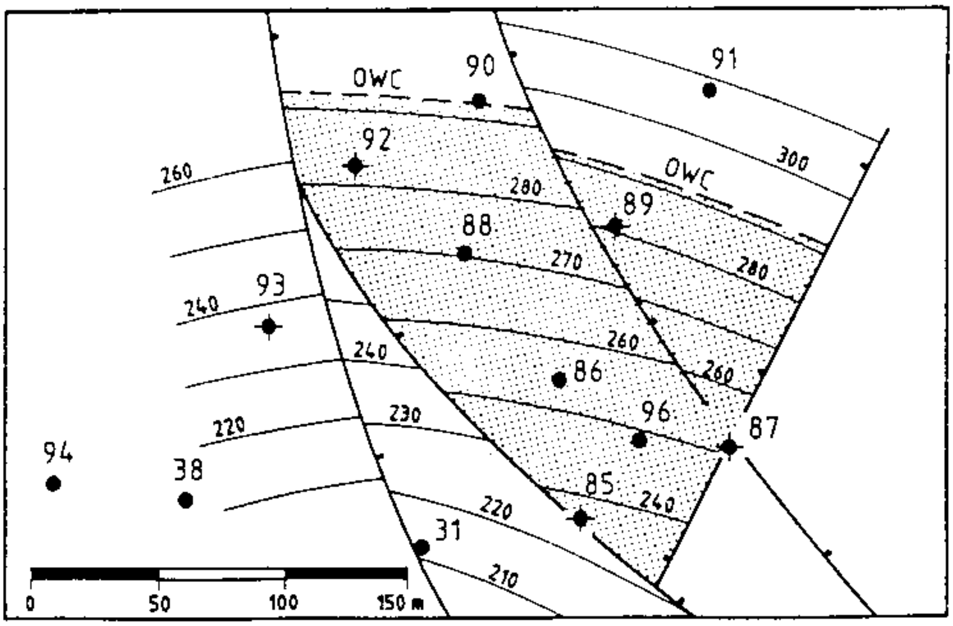

Fig. 3 Structure map of pilot area

Wealden sand M was chosen for the polymer flood, a surfactant flood is being prepared for Wealden sand I. The Wealden sand M may be divided into two layers which are seperated by a shaly sand layer. The upper layer has an average thickness of 2 m, an average porosity of 26 % and an average permeability of 1,700 μm^2, values for the lower layer are h=2m, O=22%, and k=900μm^2 respectively. The productive area is 21,200 m^2, the hydrocarbon pore volume 27,500 m^3 and the initial oil in place 21,200 m^3 under reservoir conditions. The reservoir temperature is 22 °C, the oil viscosity under reservoir conditions is about 7 mPa·s. In primary and secondary operations oil was produced only in the down dip well 90. In well 91 water was injected for a short period. During primary production reservoir pressure fell below the bubble point and a secondary gas cap was developed in the up dip part of the structure. Though well 90 is located near the oil water contact it could be produced at a water cut of 50-70%. Cumulative production in 1984 was 7,085 m^3 tank oil. The producing well 96 was drilled up dip for the polymer flood project. One objective of this well was to get fresh and representative core material for laboratory studies. The well was cored in the entire pay zone using the rubber sleeve technique.

Before starting any further investigations for the polymer flood a pulse test was performed. Good communication between well 90 and 91 was found. It was shown that the fault in NW-SE direction was not sealing. Because of the secondary gas cap the response in well 96 was not significant. It was decided to use wells 90 and 91 for injection and well 96 for production. This concept was to be checked by numerical reservoir simulation.

2.3 Numerical reservoir simulation

To obtain data for the optimum flood pattern, polymer slug size, necessary viscosity of the polymer solution, injection rates and pressures, and incremental oil recovery, a numerical reservoir simulation was performed at a very early stage of the project. For the simulation an in house developed black oil model with polymer option was used. The history match was done using a two layer model and a one layer model. As the differences in the results of these two models were not significant, the one layer model was chosen for further prediction runs.

2.3.1 History match

The results of the history match are shown in fig. 4 - 6. Only few data at beginning of production were available to match pressure development. For this reason the short water injection period before start of polymer injection was used for the history match. In this period many pressure data were gathered. The relatively good match of pressure and production data in this time period indicated that in the production statistics some values are wrong. This is supported by the fact that for time periods of several years the production data used for history matching were not measured field data, but statistically produced data. This is the reason that the difference between "measured" data and calculated data in the plot of cumulative oil production in fig. 6 in Dec. 1985 is 1000 m^3 tank oil.

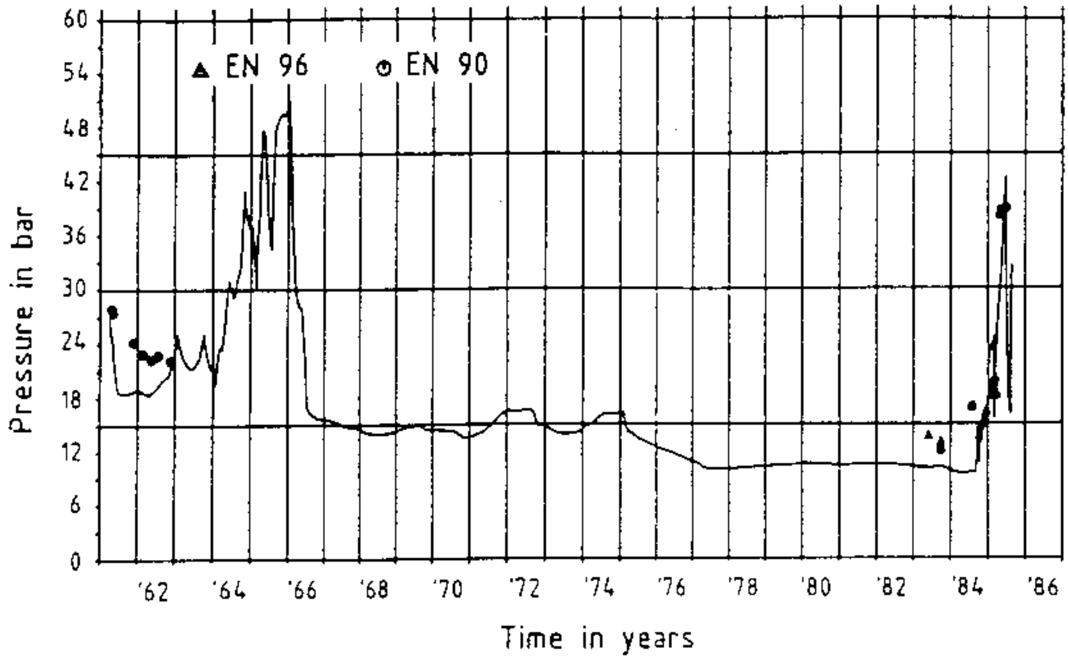

Fig. 4 History match of reservoir pressure
(lines calculated; dots measured)

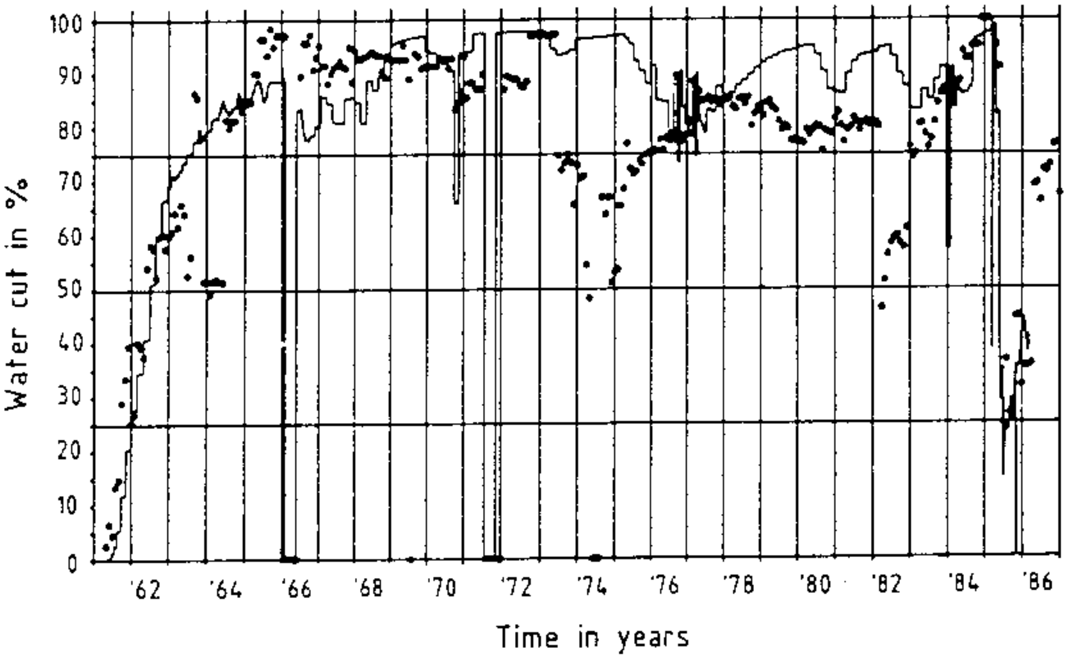

Fig. 5 History match of water cut of whole reservoir
(lines calculated; dots measured)

2.3.2 Prediction runs

Prediction runs were performed for water injection and polymer injection. Polymer injection was simulated for different polymer slug sizes and viscosities of polymer solutions. The polymer adsorption was assumed to be 20 µg/g, a representative value for Xanthan at the brine salinities and temperatures encountered in Eddesse-Nord. The results of the

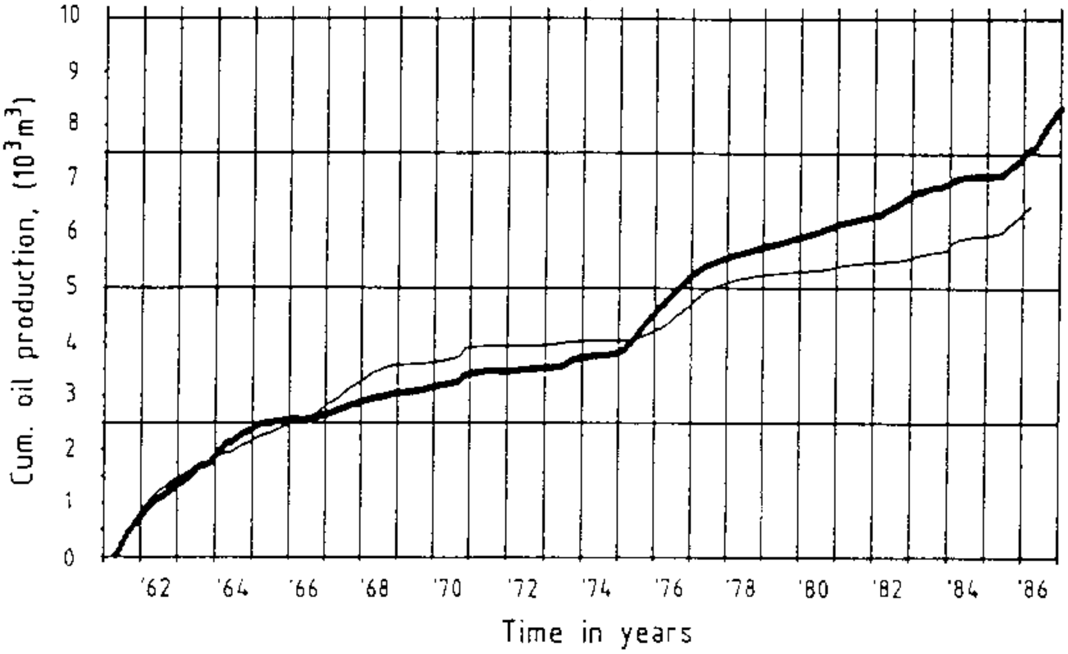

Fig. 6 History match of cumulative oil production (lines calculated; dots measured)

prediction runs were that a slug size of 0.5 hydrocarbon pore volumes and a viscosity of 14 mPa·s (2 x μ_o) would give an optimum incremental oil recovery of about 6 % of the initial oil in place at a polymer consumption of about 6 kg per m^3 of incremental stock tank oil. Before polymer injection a slug of 0.7 hydrocarbon pore volumes had to be injected to repressurize the reservoir and to dissolve a secondary gas cap that had developed during primary production in well EN 90. The best performance was obtained, when polymer was injected into the two downdip wells at EN 90 and EN 91 at the oil water contact. The possible maximum polymer injection rate was 10 m^3/d for each injection well at a maximum well head pressure of 12 bar for well EN 91 and 22 bar for well 90. The higher injection pressure at well 90 is caused by the residual oil saturation at this former production well. Well EN 91 was already initially located in the aquifer. Polymer loss into the aquifer was calculated to be about 40 - 45 % of the total injected polymer. The results of the prediction runs are shown in fig. 12 - 14 together with first results of the actual field performance.

3. Polymer

The project was scheduled as a pilot for further oil fields in Northwest Germany and so requirements to a polymer were higher than for the Eddesse-Nord field only. The polymer should be applicable in high salinity environments up to 12 %. Application in fresh mixing water was not considered because of problems with disposal of produced reservoir brines in many oil fields.

3.1 Polymer selection

Polymers that meet the above described requirements are hydroxyethyl cellulose and Xanthan. Polyacrylamides offered on the market are not suitable, and experiments within the project to modify PAA for better salt stability were not successful.

The polymers were tested with respect to their viscosity yield, injectability into sand stone cores and sand packs, filterability and long term stability.

For application in the pilot a newly developed Xanthan was chosen. The viscosity yield of this product was not as good as that of some other products in the market, but it exhibits a good injectability and filterability. In fig. 7 a plot of the viscosity yield is shown at different rates of shear strain. At a rate of shear of 10 s^{-1} polymer concentrations of 1000 - 1200 ppm are necessary to obtain viscosities of 10 - 12 mPa·s, which is the viscosity of the polymer solution injected in the field.

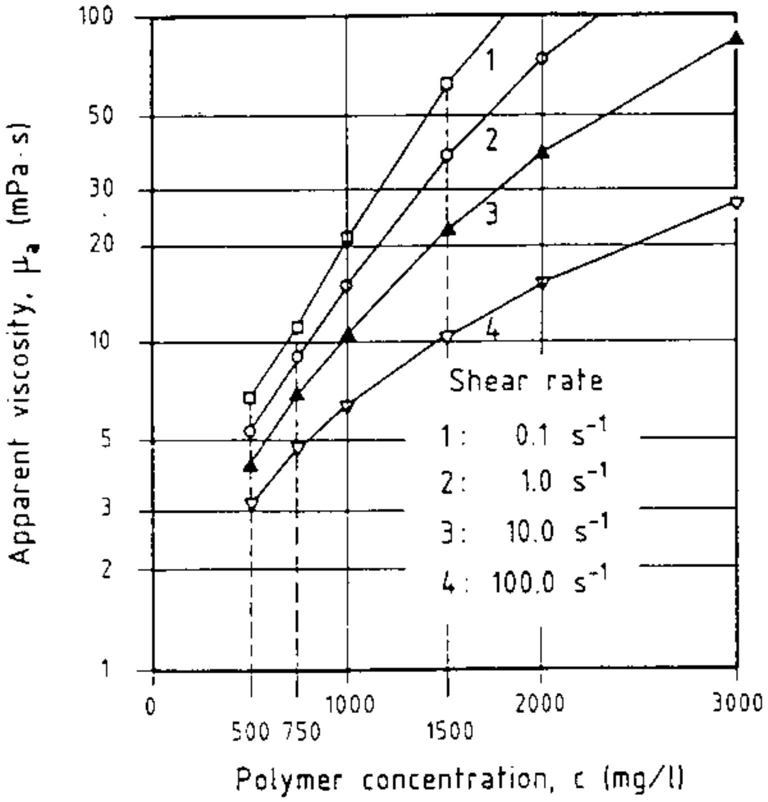

Fig. 7 Viscosity yield of Xanthan

In fig. 8 a filtration test on Xanthan solutions is shown. The tests were performed with solutions made of a dried powder and fermentation broth. The differences in injectability are significant. Injectabilities from sand pack tests using the same solutions are shown in fig. 9. These tests also show the better performance of the Xanthan broth.

Laboratory tests of the long term stability of the polymer solution showed that no problems are to be expected as long as the water is oxygen free and free of iron. Iron in the mixing water was bound with a complexing agent. The relatively low reservoir temperature promotes the growth of bacterial. For this reason formaldehyde was added to the mixing water at a concentration of 1000 - 2000 ppm.

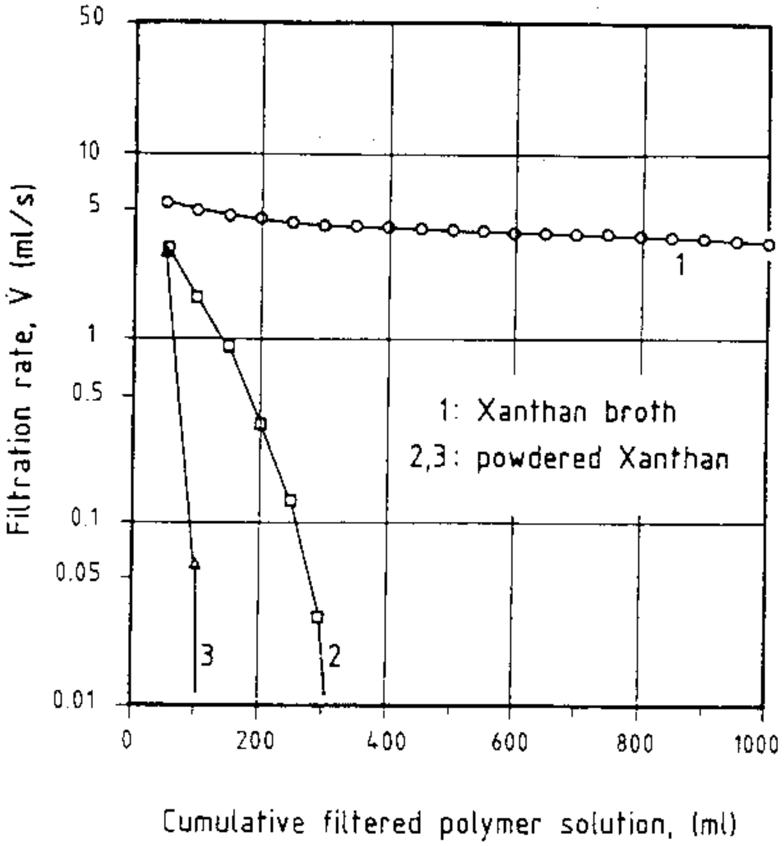

Fig. 8 Filtration curve; Millipore filter 3.0 µm

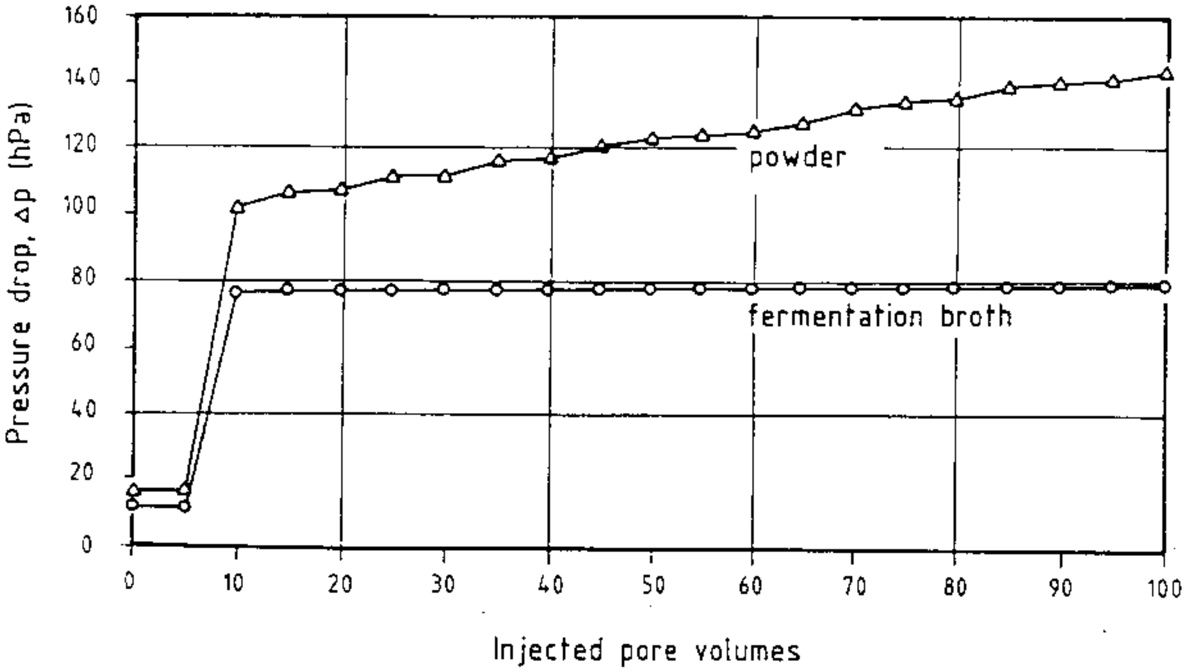

Fig. 9 Injectability test on a sand pack of Xanthan solutions made of a Xanthan broth and from a powder grade Xanthan.

3.2 Polymer mixing

Proper mixing of the polymer with the injection water is important for good injectability of the polymer solution in the reservoir. So intensive laboratory experiments were performed to find the best way of mixing. It was found that shearing of the polymer solution is necessary to improve injectability.

In fig. 10 the mixing device as used in the field is shown.

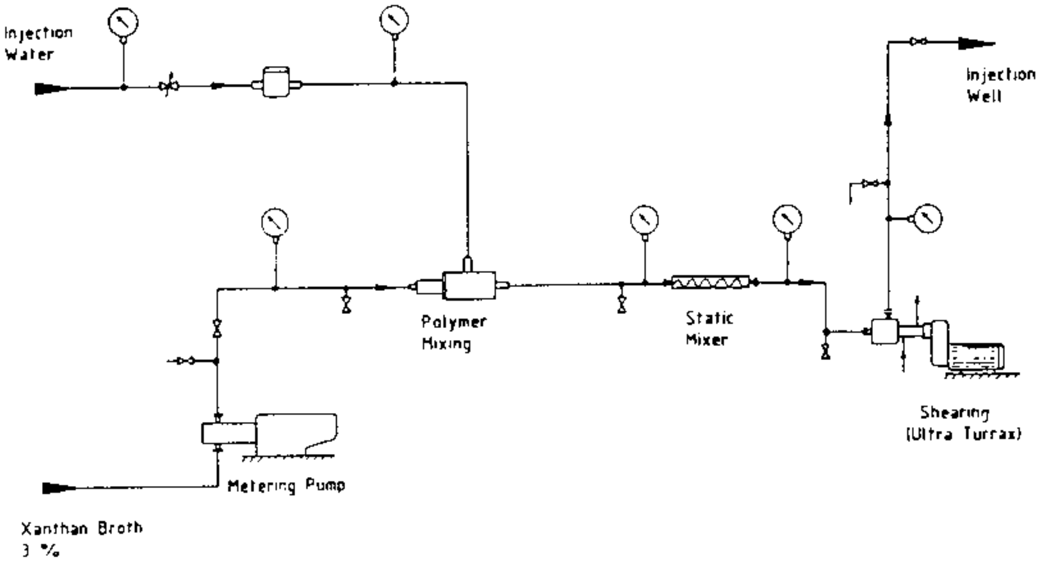

Fig. 10 Polymer mixing equipment

The Xanthan broth, having a concentration of 2-3 weight % active polymer, is stored in a 40 m^3 stainless steel tank. The tank is kept oxygen free using a nitrogen blanket. The Xanthan broth is fed to a metering pump using the hydrostatic pressure in the tank. Before the metering pump a stainless steel sieve with a mesh width of 0.5 mm is installed. This sieve is used to protect the metering pump from macroscopic particles like steel shreds, sand grains etc. which may be still present in the tank. The metering pump is a rotating piston pump, which has no valves, and thus is able to pump the highly viscous polymer broth. The polymer broth is injected into a stream of filtered reservoir brine. After that the polymer solution passes a static mixer and is then sheared in a high speed stirrer (in-line ultra-turrax). The polymer solution leaves the mixing device at a pressure of about 2 bar (200 kPa), which is enough to transport the polymer solution to the pumps at the injection wells 90 and 91. The biocide is added to the mixing water before polymer mixing.

After an injection period of 1 year it was found that shearing with the high speed stirrer could be replaced by a filtration through a filter with pore sizes of 15 - 50 µm. The effect of this "filtration" is more a shear effect than a filtration effect. The pressure drop at the filter is 1 - 2 bar (100 - 200 kPa). After more than half a year no filtrate residue was observed on the filter surface.

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4. Project performance

4.1 Water preflush

During primary production in well EN 90 a gas cap developed up dip. The mean reservoir pressure decreased during this time from initially 28 to 17 bar. So water injection was necessary to repressurize the reservoir and thus dissolve the secondary gas cap. Water injection into well EN 91 started in August 1984, and 10 300 m^3 of water were injected until November 1985.

Formaldehyde at a concentration of 2.2 kg/m^3 was injected together with the water to protect the following polymer from bacterial degredation. During water injection the production of well 90 continued, though it was producing at a water cut of nearly 100 %. The produced water was monitored for salinity and formaldehyde concentration. The initial salinity of the reservoir brine produced in well EN 90 was 122 kg/m^3. After a cumulative injection of 6000 m^3 water the salinity of the produced water decreased to 92 kg/m^3; this corresponds to an amount of 45 % of injection water, and so the formaldehyde concentration should be 0.99 kg/m^3. Actually 0.45 kg/m^3 formaldehyde were found in the injection water, so that roughly 50 % of the formaldehyde were "lost" to the formation.

As laboratory tests had shown a formaldehyde concentration of 500 ppm to be sufficient to prevent growth of bacteria that could degrade Xanthan, it was decided to continue using formaldehyde as a biocide.

4.2 Polymer injection

After a cumulative water injection of 10 300 m^3 polymer injection was started in November 1985. A Xanthan solution of 800 - 1000 ppm active polymer was injected into wells EN 90 and 91. The viscosity of the polymer solution was 12 - 16 mPa·s at

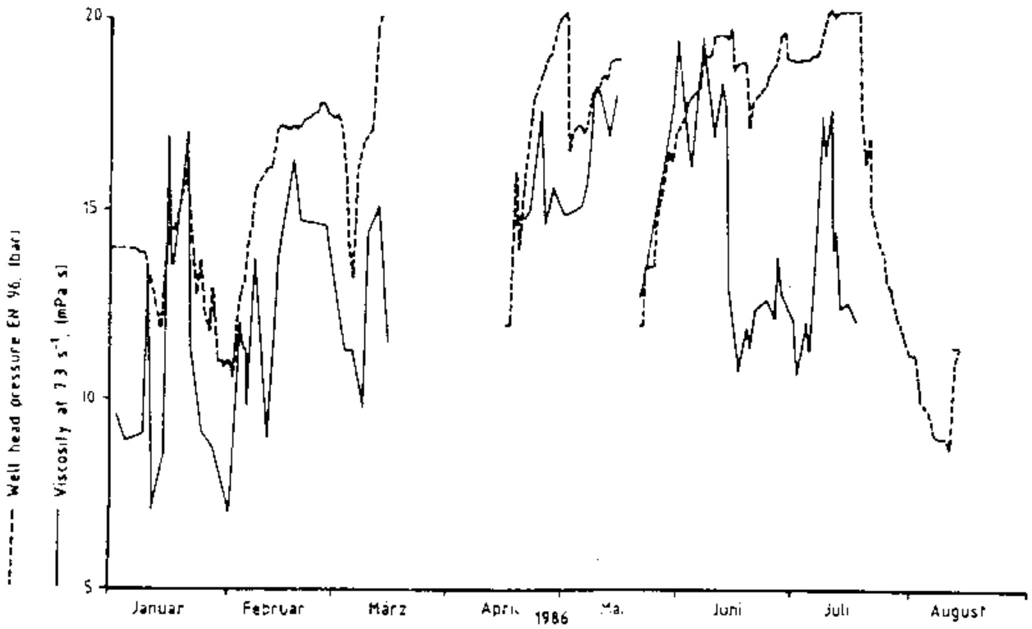

Fig 11 Viscosity of polymer solution and corresponding injection pressure at well EN 90

a shear rate of 7.3 s^{-1}. Development of the injection pressure is shown in fig. 11 together with the polymer viscosity. Injection pressure was 15 - 20 bar at the well head of well EN 90. Injection pressure correlated well with the viscosity of the polymer solution. The injection pressure of well EN 91 was about 10 bar lower than at well EN 90. Well EN 91 was originally located in the aquifer and so effective permeablility was higher than in well EN 90 where residual oil saturation was still present. Up to now no injection problems occured.

4.3 Production

Production in well EN 96 was started in March 1985. After producing 1200 $m^3(V_n)$ of gas the well could be produced at a rate of 0.5 m^3/d at zero water cut. The production rate could soon be increased to 3 - 4 m^3/d. As this production rate was relatively low (25 % of the injection rate), and a further acceleration was not possible, the additional well EN 88 was put on production in May 1986 and followed by well EN 86 in March 1987.

In fig. 12 - 14 the calculated development of the water cuts for the polymer flood and/or a comperable water flood are plotted, together with the actual data measured in these three wells.

In well EN 88 the measured data in 1986 match well with the curve for a water flood. At the beginning of 1987 a decrease in water cut from 90 % to 75 - 80 % could be observed. The response to polymer injection occured later than calculated, but it was more significant. In December 1986 a Xanthan concentration of about 10 ppm was analysed in the produced water, but higher concentrations indicating a break-through of the polymer could not be observed.

In well EN 86 the water cut is slightly lower than predicted, but it is too early to diagnose a clear response to the polymer flood.

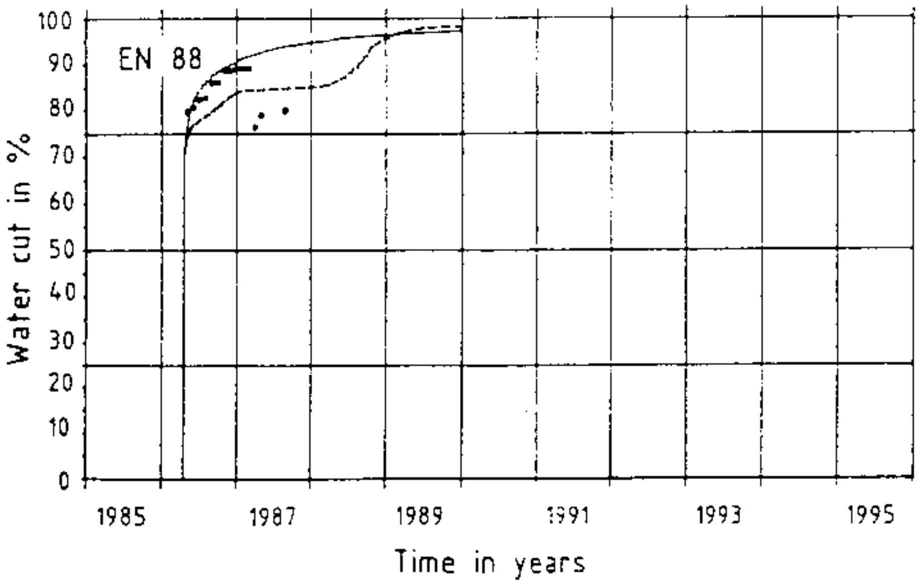

Fig. 12 Water cut in well EN 88 (line: water flooding; dotted line: polymer flooding; dots: measured values)

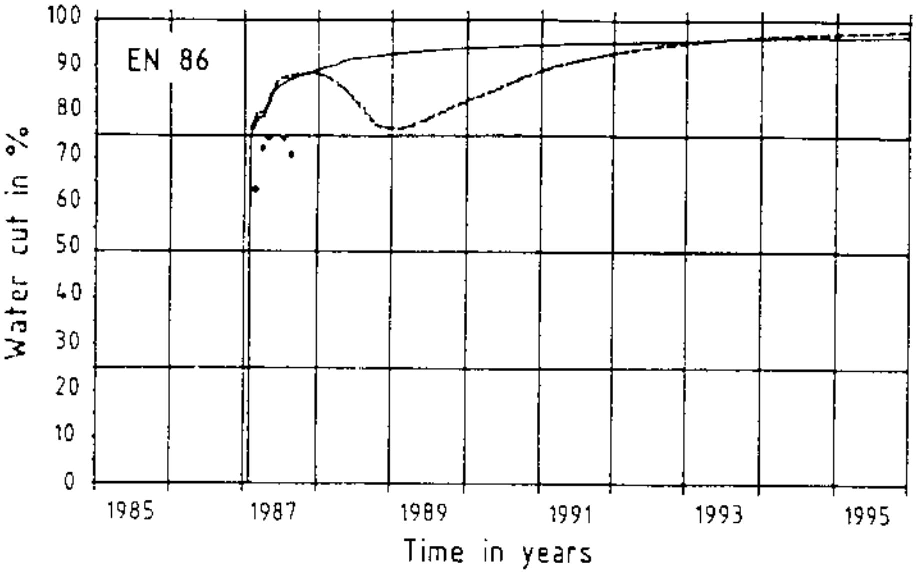

Fig. 13 water cut in well EN 86 (line: water flooding; dotted line: polymer flooding; dots: measured values)

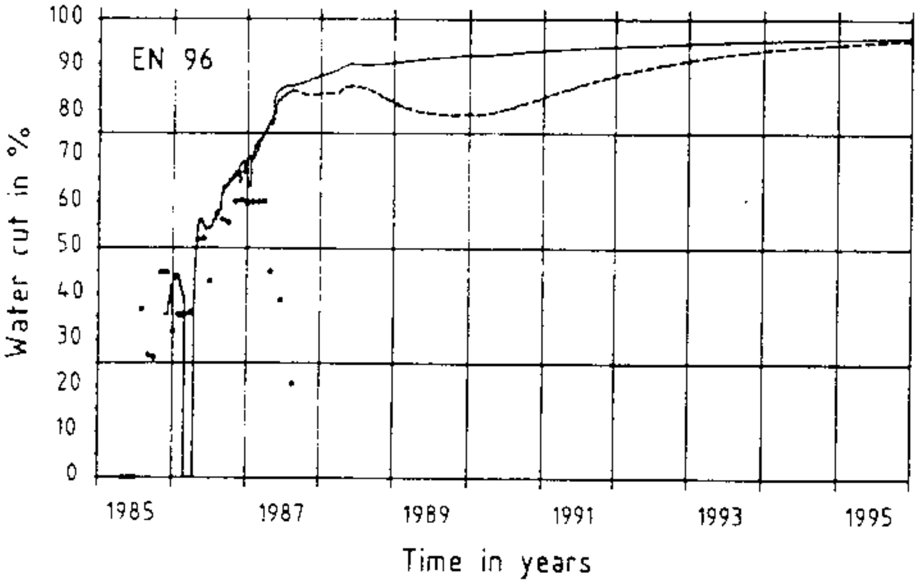

Fig. 14 water cut in well EN 96 (line: water flooding; dotted line: polymer flooding; dots: measured values)

Though well EN 96 is the most distant from the injection wells a response to the polymer flood is observed. In the beginning the measured data match well the predicted data. A significant decrease in water cut from about 60 % to 30 - 40 % was observed in March 1987.

5. Conclusions

Though polymer flooding in a reservoir block having a secondary gas cap and an aquifer was not easy to perform and unpreventable losses of polymer into the aquifer were calculated the project is a technical success. No problems in polymer injection occured, but problems were encountered in the capacity of the production wells, due to high pressure in the reservoir.