Practical Experience with Water Control in Gas Wells by Polymer Treatments

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Abstract

The paper deals with the appraisal and application of water control technologies for gas wells and gas storage wells. A laboratory evaluation of different polymer products for a variety of reservoir conditions - temperature, salinity of reservoir brine, rock permeability - was performed. For the numerical characterization of polymers, the performance factor, which is the residual resistance factor for water divided by the resistance factor of the polymer solution, was used to select the best suited products for 4 candidate wells. The investigations were performed by 3 independent laboratories DBI-GUT in Freiberg, IFP in Paris and ITE in Clausthal. Two examples of field application are presented:
The high temperature gas well Salzwedel 85, which suffered from secondary water migration through a depleted gas layer and the gas storage well Buchholz P 17 with moderate depth and temperature, in which water production periodically occurred at the end of the production period. Successful treatments could be performed in both cases and the results have shown that secondary water influx could be stopped and water break-through in a storage well could be delayed. Injectivity and productivity of the wells were improved by a reduction in friction loss in the vicinity of the well bore, presumably due to polymer adsorption.

1 Introduction

Water influx in production wells is a general problem which dominates the cost side of production. Excessive water production can result in reduced well productivity, extra corrosion, sand production and increased environmental protection costs. On the other side, water injection and aquifer expansion are vital mechanisms for oil production and pressure maintainance in reservoirs. Measures to separate the formation water from oil and gas in the reservoir have been tried for many years at different reservoir conditions, with different methods and products. J. Morgan /1/ from BP Exploration concludes from an analysis of various interventions in existing wells to slow the passage of water, that „there is no cure - all process at present and what is successful in one field, may be inappropriate elsewhere".

Y. Guerrini, N. Kohler and A. Zaitoun /2/ classify the water control methods, depending on the structure of the reservoir rock into

- permanent barrier methods
- selective barrier methods

If water and hydrocarbon zones are clearly separated, processes using permanent barriers which can be placed in the water bearing zones, generally give good results. They can be formed by injection of cements, resins or silicate gels. However, when oil, gas and water are flowing simultaneously, polymer solutions and/or gelants are injected which can block the water phase, but remain permeable to oil and gas.

Depending on the type of reservoir rock, reservoir temperature and salinity of the reservoir brine, different polymer substances can be used for blocking the water. For low salinity conditions and moderate temperatures, polyacrylamides have been often used together with crosslinking agents to form gels whereas for higher salinity and moderate temperatures biopolymers like xanthans and scleroglucanes have been applied. For very high temperatures and salinity conditions synthetic copolymers based on acrylamide (AM) and one of three possible anionic monomers like acrylic acid (AA), acrylamido-methylpropanesulfonic acid (AMPS) or acrylamido-methylbutanol acid (AMBA) with either two or three functional groups (terpolymers) can be used.

C. McCormick and R. Hester /3/ describe the structural properties of these products and A. Audibert and C. Noik /4/ describe the use for high temperature applications up to 100° C. Only a few field tests are published with respect to very high temperature conditions and for oil wells exclusively. Based on micro-model studies R. Dawe and J. Zhang /5/ interpret the mechanisms of gel barriers. They found, that water cannot easily penetrate through a gel, but that the oil phase can finger from a center of the pore through a gel by taking away some of the incorporated water and causing syneresis of the gel by shrinkage and widening of the path way for the oil phase. But gels can only be applied under preferentially water wet conditions since under preferentially oil wetting conditions the gel stays at the center of the pores and exerts a lower blocking resistance compared to the water wet porous media.

Water control in gas wells is not in common use, because of the risks of face plugging with the high molecular weight species of standard polymer solutions. This is due to the fact, that gas reservoirs and gas storages show distinct features compared to oil reservoirs:

- the mobility of the hydrocarbon phase is much higher than the mobility of the water phase
- permeabilities of the reservoir rock are often lower than in the case of oil reservoirs
- edge water drive or bottom water drive is not as common as in the case of oil reservoirs
- deep reservoirs can show very high temperatures, where liquid hydrocarbons may not exist

In a demonstration project of the Thermie programme of the European Union, a comparison of different water control technologies for various reservoir environments was the target of lab and field testing.

The main reservoir characteristics of the 4 candidate wells are shown in table 1. Case 1 to 3 represent gas storages ranking from low salinity, low temperature and high permeability up to saturated brines, high temperatures and moderate permeabilities. Case 4 shows extreme conditions with extra high temperature, high salinity and low permeability. The technological comparison of methods and substances were based on a laboratory evaluation phase and a field testing phase.

Table 1 : Characterization of Candidate Wells

	Engelbostel E 1020	Buchholz P 17	Kalle S 106	Salzwedel SW 85
Formation	Wealden	Middle Bunter (Detfurth)	Middle Bunter (Volpriehausen)	Rotliegend
Rock Type	Sand-/ Siltstone Interbedding	Sandstone	Carbonatic Siltstone	Sand-/ Siltstone Interbedding
Temperature [K]	295.0	307.0	360.0	395.0
Salinity [kg/m^3]	45.0	218.0	300.0	330.0
Av. Porosity [%]	26.0	17.8	19.5	13.4
Av. Permeability [$10^{15} m^2$]	1270.0	590.0	100.0	11.0

2 Laboratory Appraisal of Chemical Systems

In the case of low to moderate permeability gas reservoirs or gas storages only low molecular weight polymer solutions are injectable. However the gelification of a polymer solution needs a minimum polymer concentration to proceed. For low molecular weight polymers the critical concentration is rather high and the use of gel formulation with these polymers becomes soon uneconomical. Therefore, polymer adsorption technologies are the preferential way to control the water flux in gas bearing formations. These effects can be achieved by polymers being strongly adsorbed on rock surfaces and entrapped in the network of the pores. The corresponding performance indicator is the residual resistance factor (RRF) for water after polymer adsorption has taken place and the excess polymer has been displaced by the formation brine. The base value for defining the residual resistance factor is the water permeability of the brine saturated rock. The procedure is described in reference 6. The residual resistance factor for the gas phase is determined by removing the excess polymer phase from the pore network by flooding with the gas phase and measuring the effective gas permeability at residual polymer saturation. The base value is the effective gas permeability at residual water saturation before polymer flood. Facing the lack of fresh core material, and the fact, that core material from the corresponding fields was very rare and in a bad condition, only crushed cores could be used for the laboratory evaluation tests. Since permeability is a very important parameter in the appraisal of the retardation effects for water and gas flow, model sandstones have been chosen, which represent the permeability and porosity class of the corresponding mean values for the candidate well. The properties of the encountered model sandstones Bentheimer, Obernkirchner and Vosges Sandstone have been described in references 7 and 8.

The appraisal of the different polymers used for the adsorption process is based on the comparison of the so called „performance factor" of the polymer, which is the reciprocal mobility factor. The mobility factor is a criterium for judging polymers for enhancing oil recovery through mobility control and should be reasonably high to balance the mobility factor of the oil phase. For selectively controlling the flow of water, the performance factor should be characterized by a very high retardation effect for the water phase (RRF high) and good injectivity (RF low).

The polymers, which have been used in the laboratory appraisal are listed in table 2. Fig. 1 shows the results of the investigation explaining that for the low temperature environment a cationic polymer Praestol 644 was the most effective, whereas in the high temperature environment the terpolymers Hostadrill 2825 and Hostamer 3212 with the higher molecular weight showed the highest yields. Based on the suitability of these products their application was decided by the consortium.

Table 2 : Characterization of Polymers Used

Trade Name	Actigum CS 11	AN 113 HMW	FO 3150	Hostadrill 2825	Hostamer 3212	Poly-Quat	Praestol 644
Type	Sclero-glucane	Copolymer AM/AMPS	Copolymer AM/CAM	Terpolymer VA / AM / AMPS	Terpolymer VPS / AM / AMPS	Quaternary Ammonium Salt	Copolymer VA / CAM
Manufacturer	Sanofi	Floerger	Floerger	Hoechst	Hoechst	Katpol	Stock-hausen
Av Molecular Weight, Dalton	(5-7) $*10^6$	(2-3) $*10^6$	1 $*10^6$	5 $*10^5$	1 $*10^6$	1 $*10^5$	5 $*10^6$
Sulfonate Content, %	-	13	-	50-70	30-45	-	-
Polarity	Nonionic	Anionic	Cationic	Anionic	Anionic	Cationic	Cationic

3. Field Test Appraisal

Strategy of Application:

Depending on the reservoir characteristics, - sandstone reservoirs with intergranular porosity-, the origin of the produced water and technical limitations of the treated wells, gel treatments of the candidate wells could not be used. Polymer ad sorption water control methods in combination with low permeable rocks or moderate permeability formations, have been selected for the field tests. Two groups of products - anionic terpolymers and cationic copolymers have been applied in 4 field tests (characterization of polymers in table 2).

Case Study Salzwedel 85

The gas field Salzwedel-Peckensen is located in the state of Saxony-Anhalt, east of the city of Salzwedel in a depth of roughly 3500 m. The gas bearing formation, the Rotliegend Series, has a thickness of more than 40 m and consists of rhythmic series of silty - clayey - fine sand layers. The gas field extends nearly 100 km to the east and is one of the biggest on-shore gas fields in Europe. But gas productivity of the wells corresponding to a permeability of less than 10 mD is low and the nitrogen content increases from west to east up to 70 %. An active water drive is not existing, but water production with a high salinity of more than 300 g of salt per liter, frequently occurs and terminates the gas production of the depleted gas bearing layers. It is estimated that the water influx is caused by conductive fracture systems, which are interconnected to a bottom water layer through some thief zones in the reservoir. Periodical water production is not uncommon due to the dependency of fracture conductivity on effective stress conditions.

The well bore situation of the candidate well Salzwedel 85 is shown in fig. 2. The net thickness of the productive layers A - D was 44.2 m, the reservoir pressure of the infill well (late phase of recovery) was 19.8 MPa and the initial production rate was 400 000 m^3 per day. Water production was not a serious problem until in 1989 highly saline brine was produced from the bottom layer D (fig. 3). The well was shut in for nearly half a year. During this time a secondary migration of water might have taken place into the low pressure reservoir A and probably B 14 (fig. 2). The layers A and B 14 contain some high permeable sand strings of some decimeter of thickness and permeabilities in the range of 50 to 100 mD. The well could be brought back into production, but the productivity had decreased to 240 000 m^3 per day, due to the reduced formation pressure of less than 16 MPa. The intermittent gas production was not very satisfactory, so it was decided to stimulate the well by a water control treatment. The primary water influx should be controlled by a cement bridge and the secondary invasion by a polymer adsorption barrier. The diagnosis of the water influx was based on a drill-stem test. The well bore was cemented to 3365 m (cement head 1), before the polymer injection. In order to establish a good injectivity for the polymer solution, the perforations of layer A and B 14 were washed by acid treatment, and the polymer solution consisting of 200 m^3 with an average concentration of 800 mg/l based on active nitrogen content was injected in one slug (fig. 4).

An initial well head pressure of 16 MPa was necessary to maintain a rate of 7 m^3 per hour with a decreasing tendency of well head pressure down to 5 MPa. The polymer solution was displaced by a low concentration Tixoton mud into the formation. The cement bridge was opened by drilling to 3388 m below the horizon C 11 (cement head 2 in fig. 2). Packerless tubing was installed and the Tixoton mud was circulated from the well, using water and cleaning the formation entry with a surfactant solution. After a gas stimulation of the perforation intervalls, the well was produced with 100 000 - 120 000 m^3 per day over a period of 2 years without any detrimental water influx. Figure 3 shows, that the salt concentration remained low. So mainly condensed water is produced.

The theoretical amount of injected polymer was determined with 198 kg, whereas the injection profile gives a total mass of 160 kg. The backflow of water produced a mobile polymer mass of approximately 70 kg.

Two production control measurements have been performed after the polymer treatment in order to prove that the mobile water in layer A and B 14 remained immobile after the polymer treatment. In fig. 5 the situation is shown 5 months after the treatment, explaining that 90 % of the produced gas is coming from layers C11, 12 and B 13, whereas the high water content in layers A and B 14 does not affect the production. Some 10 % of the produced gas was identified by flow-meter measurement from layer B 14, which had been treated with the polymer solution. Technically and economically this test proved to be a success.

Case Study Underground Storage Buchholz, P 17

The gas storage Buchholz, operated by Verbundnetz Gas AG (VNG) is located southwest of Berlin, in a depth of approximately 650 m. The reservoir consists of a relatively thick sandstone layer (Detfurth Sandstone) of the Middle Bunter, with a net thickness of 18 m and an average permeability of 590 mD. The reservoir had been used as the storage for „Stadtgas“ in the former GDR and is currently be used for the storage of import gas from Russia.

Injection and production of gas is characterized by several problems, coming from the high saline reservoir brine with 218 g/l and frequently occurring wellbore plugging through bacterial activities of sulfate reducing species. Acid treatments are always necessary in order to maintain the injectivity and productivity of wells. The origin of water production is also not quite well understood, but it could be identified, that water production is mainly attributed to a definite stage of unloading of the gas storage as it is often observed with bottom water drive or fracture induced water influx. The well bore characteristics are shown in fig. 6. The pay zone of the Detfurth Sandstone is completed with a gravel pack , the production is maintained through a 3.5 inches tubing string packed of from the annulus of the 6 5/8" casing in the depth of 593 m. Before the polymer treatment in August 1993, the well was cleaned by acid treatment to remove plugging from bacterial activities. 200 m^3 of a cationic polymer Prestol 644 were injected with a tapered slug shown in fig. 7. The injected amount of polymer, which was mixed with fresh water with an addition of 20 kg sodium chloride per m^3 of polymer solution in order to improve the injectability by viscosity reduction, equals to 225 kg. The produced concentration of polymer is also shown in fig. 7 and the amount was calculated with 12 kg.

The selection of a cationic polymer was favoured by the presumably antibacterial effects of this type of polymer. The injection was controlled with a maximum well head pressure of 2 MPa and a corresponding rate of 6 m^3/h. The polymer solution was displaced from the tubing with a sodium chloride solution (20 kg/m^3). Gas injection could be restarted after displacement of the fluids from the injection lines without problems.

The adsorbed polymer has apparently improved the injectivity for gas as it can be seen from fig. 8 by some 15 % of increase. Also the gas productivity was increased in the following production period for some 45 %. But bacterial activities could not be stopped by the cationic polymer as it can be seen from fig. 9. An acid treatment was necessary in September 1994 in order to improve the low injectivity of the well. Immobilization of formation brine was not expected, as it happened in the gas well Salzwedel 85, but a delay of water influx was a target of the treatment with the cationic polymer. A comparison of the result of treatment in the gas storage well is not easy, because storage and production figures change from season to season according to the demand of consumers and changing deliverables of the wells.

So only the situation after the polymer treatment can be analyzed. In fig.10 a delay of water influx is shown. Some 1.5 million m^3 of excess gas could be produced presumably due to the water controlling effects of the polymer treatment. At the end of production 1994 the gas saturation after polymer treatment is remarkably high, as it can be seen from fig. 11, compared to the situation in the year before, where the well produced water immediately after begin of the gas production, favoured by a near well bore gas - water contact in this season.

Comparison of Results

Both well treatments proved to be successful with respect to their technical and economical targets. A penetration radius of 5 to 10 m of the adsorbing polymer solutions is required to reduce the mobility of formation brine in order to avoid excessive water production. The residual resistance factors of the polymers used were 3.1 in the lab evaluation with Bentheim sandstone for the gas storage Buchholz with the formation characteristics of moderate permeability (590 mD) and low temperature (307 K) and equally 3.1 for the model sandstone Vosges 1, for the reservoir characteristics of the Salzwedel gas field with low permeability (11 mD) and high temperature (395 K). The amount of retained polymer ranged from 20 to 28 mg/kg of rock in the case of Salzwedel to 26 mg/kg in the case of Buchholz.

4 Conclusions

In this paper a comparison of water control methods based on adsorption of polymer for different reservoir conditions was performed and an appraisal of technologies is presented. The evaluation is based on lab experiments and field experiments. Even when the results have not been completely obtained, since monitoring of wells is continued, the following conclusions can be drawn:

- water control in gas producing and gas storage wells is possible

- polymer treatments based on adsorption technologies are of low technical risk
- for successful treatments an accurate diagnosis of water influx is required
- in pressure sensitive formations (depleted reservoirs) and gas storages with risks of sand face plugging, polymer adsorption technologies are recommended
- in the case of deep, high temperature wells, the best polymer products are terpolymers of anionic character and co-polymers of cationic character for low temperature wells respectively
- a good performance of the treatment needs a good injectability (low resistance factor) and a high water residual resistance factor
- injectivity and productivity of storage wells was remarkably improved between 15 and 45 % by a reduction of friction effects in the formation presumably through the polymer adsorption
- the water production in the storage well after the treatment was delayed. Formation brine under low pressure gradient flow regimes can be immobilized by the injected polymer solution, provided that the water channels are isolated through low vertical permeability of the formation.

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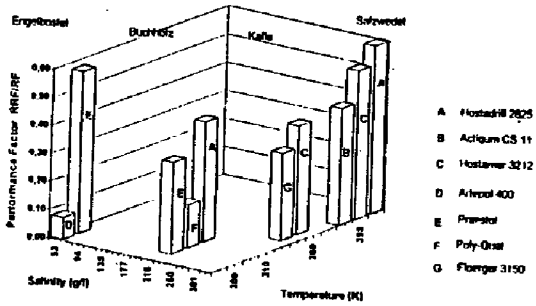

Fig. 1 Laboratory Results of Polymer Evaluation - Water Control Treatment in Gas Wells

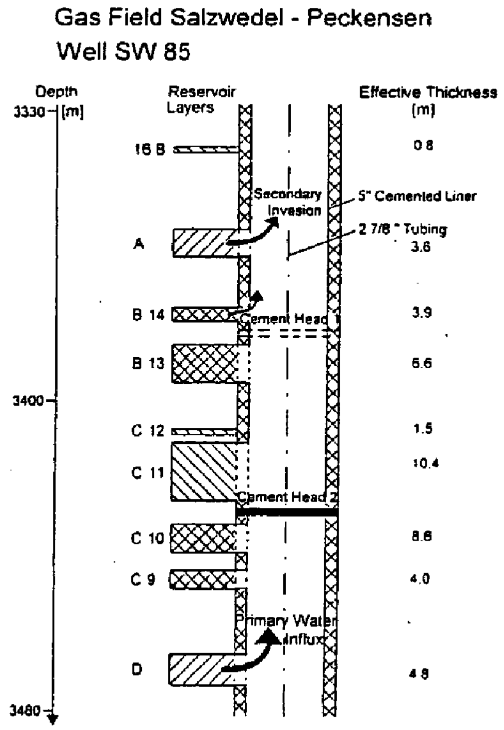

Fig. 2: Wellbore Characterization SW 85

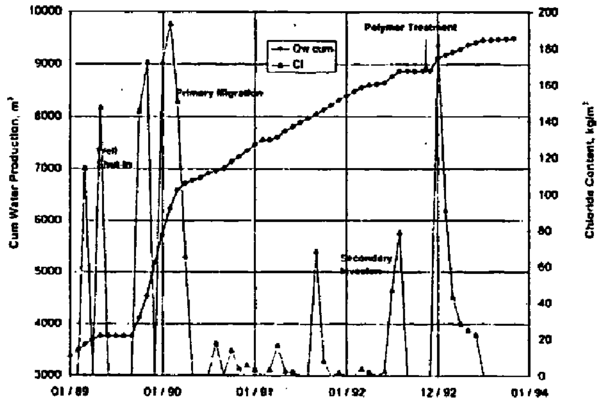

Fig.3: Production History of Well SW 85

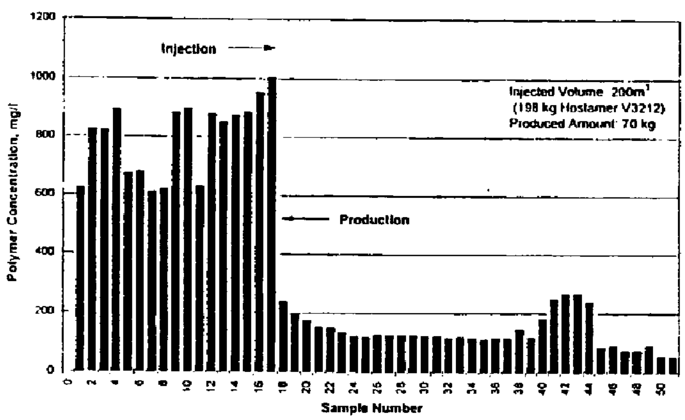

Fig. 4: Concentration Profile of Injected and Produced Polymer, SW 85

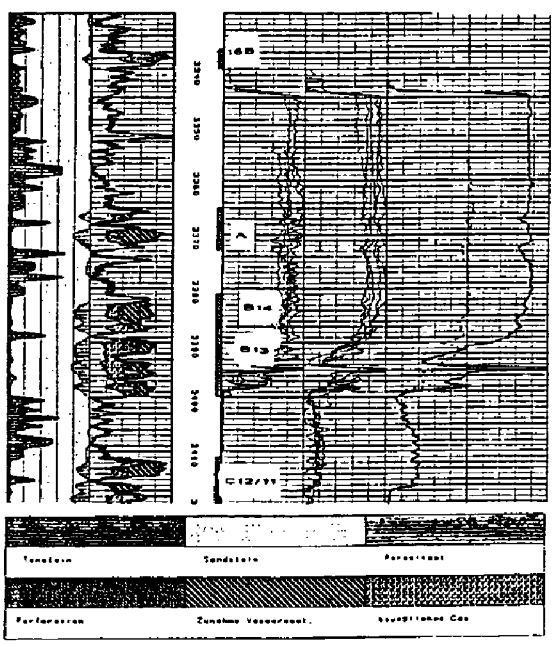

Fig. 5 :Production Control Measurement SW 85

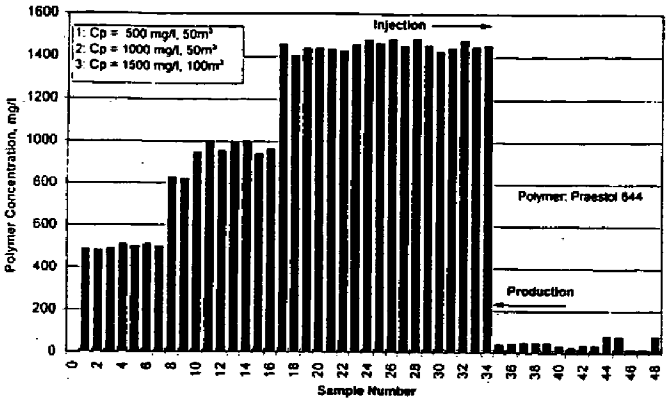

Fig. 7: Concentration Profile of Injected and Produced Polymer, Buchholz, Bz P 17

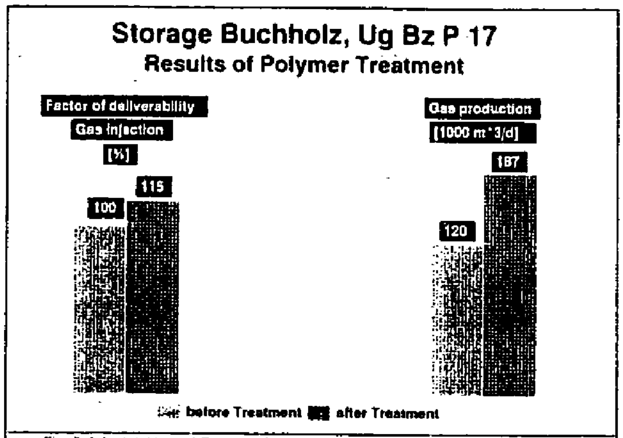

Fig. 8: Injectability and Productivity Improvements by Polymer Treatment

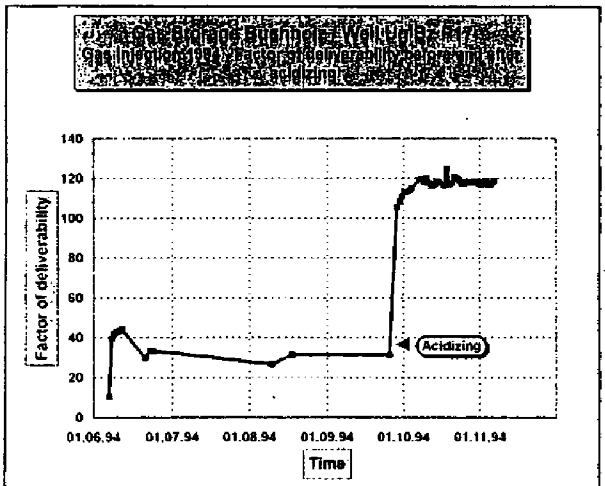

Fig. 9: Well Problems after Polymer Treatment Bz P17

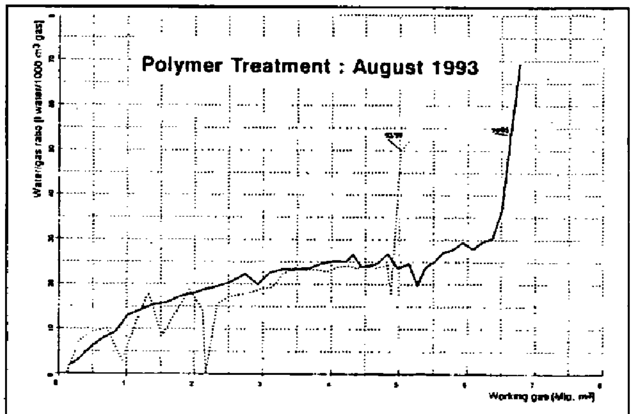

Fig. 10: Water-Gas Production Bz P17

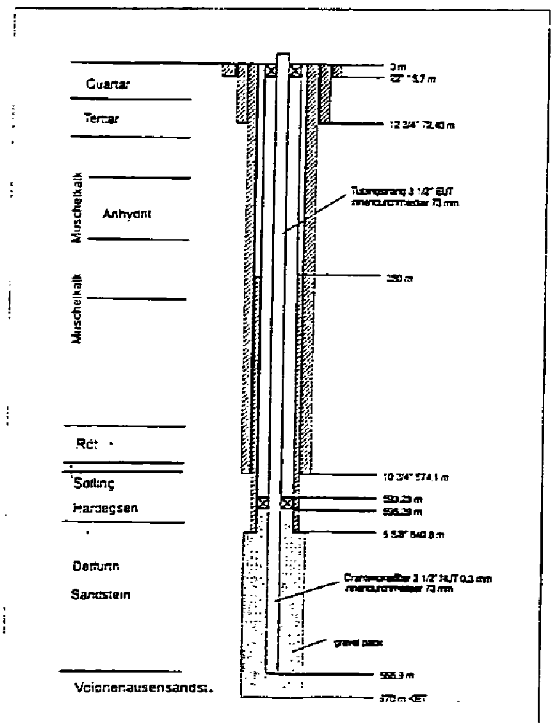

Fig.6: Wellbore Characteristics Buchholz P 17

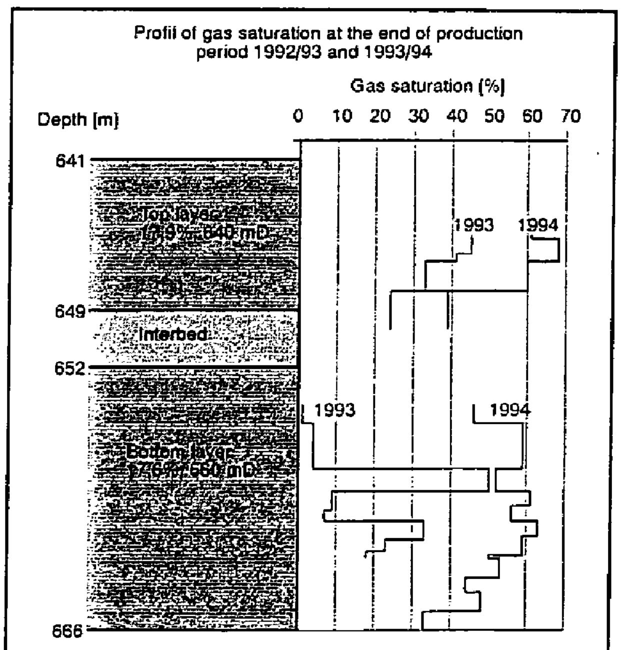

Fig. 11: Gas Saturation Profile Well Buchholz P17