003 SELECTIVE FLUID SHUT-OFF TREATMENTS AT THE ALGYÕ FIELD, HUNGARY

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Abstract

The paper analyzes the field results of different selective fluid shut-off treatments carried out at the largest Hungarian oil field during the past decade. The polymer/silicate method was routinely and profitably used for water shut-off in oil producing wells. Recently a novel method based on is-situ hydrolysis and flocculation of inorganic compounds is tested with the same goal. A complex foam/gel double injection technique was developed and used for restriction of gas conning in oil producing wells. Restriction of water conning and side invasion by injection of alcoholic polymer solutions into gas producing wells is also in the centre of field management. Although diverse experiences were obtained, the positive results and the substantial oil production encourage the experts to continue the laboratory and the field studies and to implement prospectful methods.

Introduction

Converging field experiences unequivocally prove that profile corrections in layered or highly heterogeneous porous systems with limited cross-flow may influence significantly the displacement mechanism and as a result substantial amount of oil might be produced. During the past decades the treatment of oil producing wells has shown outstanding records in practice and that fact accelerated not only the research activity, but also the field pilots and routine applications. Accordingly, the "blocking", "sealing", "profile correction", "water shut-off", etc. treatments represent today a standard world-wide service at oil fields. On the other hand, the high water cut in oil producing wells is not only a sole problem of the overall field management. It is well known that the high GOR in gas capped reservoirs or extensive water production in gas fields or underground gas reservoirs with active aquifer raise also serious issues on selective restriction of certain components of the fluid phases. Unfortunately, the later areas of well service are much less developed than those methods used for water shut-off in oil producing wells. Since the selective restriction of gas or water production in certain cases is highly desirable, and the potential of such techniques is gradually increasing with depletion of reservoirs, their R&D activity is in the forefront of the present efforts. The paper gives a brief summary of the laboratory and field studies at the Algyõ field, Hungary, which have simultaneously difficulties at all areas mentioned above and need urgent technological improvements to maintain the production rate at the present level.

Reservoir Description

The Algyõ field, discovered in the early sixties in south Hungary, is the largest Hungarian hydrocarbon field. Special feature of the multilayered reservoir is that some layers have measurable gas cap. Table 1. lists the basic parameters of the system. Production at the field began in 1965. In the primary stage only the formation energy was used. Later, the production technique included partial water flooding and gas lifting. Today, double-sided water flooding and extensive gas lifting are the mainstays of the technology. In the primary stage 5-10 % recovery factor was attained, and it is thought that the recovery efficiency today exceeds 40 % OOIP.

The oil production topped in 1989 with more than 1 Mt/y. Since that time the annual oil production shows decreasing tendency. In 1995 the oil production totalled at about 0.7 Mt/y. The water production started at the field in 1971 and it reached top rate with 4-5 Mm^3/y between 1989 and 1994. Similarly, the water injection was at its maximum in 1989 with 8-9 Mm^3/y. Consequently, the oil production was practically free of water until 1973, then the water production gradually increased in the period of 1975-1988. At the present time the average water cut stabilized at 75-80 %, but there are hundreds of wells which already operate with water cut higher than 90 %. Similar difficulties come from the fact that some oil producing wells are characterized by high GOR and extensive water production is tested in the gas producing wells.

Since 1975 the Algyõ field has been in the focus of different chemical EOR/IOR programs. Although an intensive study of different EOR methods addressing the whole reservoir space are still in the centre of present efforts, the local stimulation of wells represent more attractive alternatives for the operator. Among others profile correction, water and gas shut-off, dewaxing, clay stabilization, etc. methods were implemented at industrial scale. In the present paper, however, only the seletctive fluid shut-off treatments will be discussed in detail. Since the restriction of gas conning in oil producing wells using a combined foam/gel technique and restriction of water production in gas producing wells using alcoholic polymer solutions were performed recently, preliminary information, concerning mostly the principles and the surface technology, will be presented.

Table 1. **Characteristics of the Algyõ field, Hungary**

Depth, m	1900 - 2000
Thickness of pay zone, m	20 - 25
Porosity, fraction	0.15 - 0.25
Permeability, mD	100 - 500
Temperature, °C	92 - 95
Pressure, MPa	19.5
Rock type	sandstone
Oil type	light paraffinic
Water type	Na-hydrogen carbonate
Gas type	basically CH_4

1. Water shut-off treatments by the polymer/silicate method

The polymer/silicate technique is a multifunctional profile correction method based on simultaneous cross-linking and polymerization of hydrolized polyacrylamide and sodium orthosilicate, respectively. This procedure was already detailed in earlier publications [1,2]. The high efficiency of its chemical mechanism is attributed to parallel chemical reactions taking place in the mixing zones which jointly enhance the permeability reduction. The gel formed under appropriate condition is temperature resistant up to 150 °C, its residual permeability is less than 0.1 mD, and the mechanical stability (gel strength) is better than 10 bar/m. Formation of an organic and an inorganic network, mechanical entrapment of microgel domains, precipitation of some inorganic compounds and sorption phenomena of macromolecular materials in the pore space are the main factors influencing the permeability alteration leading to profile correction and thief zone exclusion. Generally, the composition of treating fluids are as follows:

Solution A : 1-2 g/l PHPAA
10-50 g/l SiO_2 containing water glass
Solution B : 2-5 g/l alum
2-5 g/l $CaCl_2$

Between 1981 and 1987 16 oil producing wells were treated with the polymer/silicate methods. The treating solutions are usually injected sequentially into the reservoir without mechanical diverting tools

(packers). In Solution B appropriate amount of HCl serves to prevent prematured hydrolysis of alum and then to propagate the polymerization of silicates. On average 0.5 t polymer, 10 t SiO_2 containing water glass, 0.4 t alum and 0.2 t $CaCl_2$ were used in a single treatment.Prior to treatment all wells were characterized by extremely high (>95 %) water cut. The probability of success was nearly 50 %, viz. the water cut decreased after the treatment minimum by 5 %. The responses of wells were very different: sometimes the positive effect was short, but pronounced, sometimes it was long-lasting and sporadic. The best results were obtained by the repeated treatment. In this case the total surplus oil production was close to 50.000 t oil and both the oil production and the change of water cut shown regular behaviour (Figs 1. and 2.). The cumulative oil production reached its top in 1987 and as it is shown in Fig. 3. substantial surplus oil production is also obtained in the tailing period, many years after the treatments. On average the additional oil production per treatment was about 5500 t, which corresponds to >40 recovery rate of expenditure. At the end of 1991 the totalled surplus oil production exceeded 100.000 t and the project was considered as one of the most profitable field programme implemented at the Algyõ field.
The oil producing wells treated in the frame of the project were located in the north-western section of the Algyõ-2 layer and they were sided by water injection wells. Recently, a decision was made with the aims at completing the program and including all producers into the treatments. Thus, 10 new wells were treated with the polymer/silicate method between 1995-1997. At the present time only preliminary results are available for the individual performance of wells, but the general consequence of the systematic treatments is that the well pattern consisting of a single producer row sided by two injector rows may replace successfully a flooding technology addressing the whole reservoir space.

2. Water shut-off treatments by in-situ hydrolysis and flocculation of iron compounds

Development of a new well treatment method was stimulated by recognizing that some inorganic compounds of transition metals can be transformed into gel-like precipitate by in-situ hydrolysis which is then immobilised by in-situ flocculation or spontaneous ageing [3]. The laboratory studies were extended to Fe(III), Al(III) and Cr(III) compounds, while alkaline materials and low molecular weight polyacrylamides were used as hydrolysing agents and flocculants. It was definitely proved that the novel technique is an effective method for permanent permeability reduction even in highly permeable porous systems. The blocking material, particularly the Fe(III) hydroxide or oxy-hydroxide gels have excellent thermal stability and in case of technological failure the gel phase can easily be broken into mobile sol. Further, the method is characterized by outstanding placement selectivity, self-controlling chemical mechanism and injectivity problem may not arise even in low permeable (< 50 mD) porous systems.
In 1995 two oil producing wells were selected for field tests. Taking the reservoir properties and the production history into account a shallow and a medium penetration was proposed for wells Alg. 840 and Alg. 841. The treatments were carried out at the end of 1995 using the following amount of chemicals:

	Alg. 840	Alg. 841
Solution A	280 m^3	120 m^3
$FeCl_3$	2.8 t	1.2 t
cc. HCl	1.4 m^3	0.6 m^3
Solution B	420 m^3	180 m^3
K_2CO_3	4.6 t	10.9 t
Polymer	0.4 t	0.2 t

Sequential injection of the treating solutions was carried out by a mobile surface technology deployed at the well site. Injectivity problems and other technical difficulties were not encountered. Completing the treatment the wells were shut-off for 3 months.

After the relaxation time the Alg. 840 well could be produced without problems. In case of Alg. 841 some difficulties were met and the well structure had to be repaired. After service the well was opened

in the second half of 1996. Analysis of the produced fluid proved definitely that iron compounds can not be detected in the aqueous phase ($c_{Fe} \approx 2$ ppm), viz. the fluid is produced from an intact region of the system (Fig. 4). The positive effect of treatment is case of Alg. 840 is obvious and it shows gradually improving tendency (Fig. 5). Although such a positive indication in well Alg. 841 can not be fixed at the present time, the behaviour of wells located in highly water saturated environments reason the optimistic expectation. In order to enlarge the statistical basis of such treatment 8 additional wells, 4 producers and 4 injectors, located face-by-face were treated in the middle of 1997. Thus reliable results covering these treatments will be available in the next year.

3. Restriction of gas conning in oil producing well and restriction of water production in gas wells

Extensive gas conning in gas capped reservoir is one of the most serious engineering problem hard to overcome. Cyclic operation of wells may provide temporal solution, however, gradual depletion of the oil bearing layer makes this technique less profitable. Great efforts have been made to cure this problem using different foams, but method firmly approved by field tests, are not reported.
Since the gas conning represents also a serious technological problem at the Algyõ field, intensive R&D program was initiated nearly a decade ago in Hungary. As a first step, a double-point injection technology was developed. The basic element of this method was an auxiliary perforation located 3-5 m above the GOC which served for placement of the gel-forming liquids, meanwhie the original perforation located in the oil bearing zone was used for simultaneous water injection. Depending on the volume injected, the efficiency of "supporting" properties of water and the gravitational effects a horizontal barrier shading the migration route of gas could be formed close to GOC. In 1990 two oil producing wells were treated in the Csongrád-D-2 layer using the polymer/silicate gel system. Details of this methods and the field pilot were presented earlier [4]. Unfortunately, the efforts were basically futile mostly because the production were hindered by hydrate formation at the well head. Since the gas conning is still an up-to-day problem, the method was then further studied. The main feature of modification is that foam generated in-situ by simultaneous injection of protein-containing tenside solution and nitrogen replaces the water as supporting media. Schematic of the most expensive well pilot ever made at the Algyõ field is shown in Fig. 6. The following amount of chemicals were injected into the Alg. 480 well located in the Csongrád-D-1 layer:

KCl	:	2000 kg
HC-2 tenside	:	1000 kg
Protein	:	200 kg
Formaldehyde	:	300 l
Polymer	:	200 kg
Silicate	:	17 t

The treatment was completed with sophisticated control and measurement facilities and pre- and post-hydrodynamic measurements aided the evaluation of performance. At the present time the well is in relaxation stage and it will be opened only in Sept. 1997.
Similarly, the restriction of water production in gas wells represent also crucial task at both natural gas fields and underground gas reservoirs. Encouraged by some positive field tests in Germany and theoretical conclusions on the selective effect of polymers on gas and water permeability in porous media, a method based on injection of polymer solution was tailored to the local circumstances at the Algyõ field. Differently from the procedures reported in literature an alcohol containing polymer solution was used for treatment of 4 gas producing wells and nitrogen post flush was applied to disperse the treating fluid and to dry the adsorbed polymer film. At the moment the wells start to produce the gas and the final outcome of the treatments will be evaluated in the second half of 1997, meanwhile extension of the project for additional 4 wells is under way.

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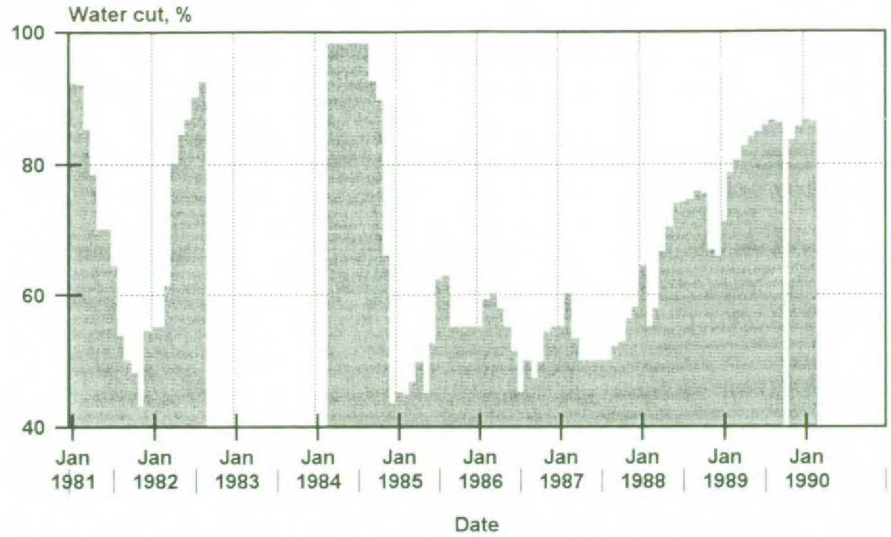

Fig. 1. Effect of "Polymer/Silicate" treatment on water cut (Well Alg. 234)

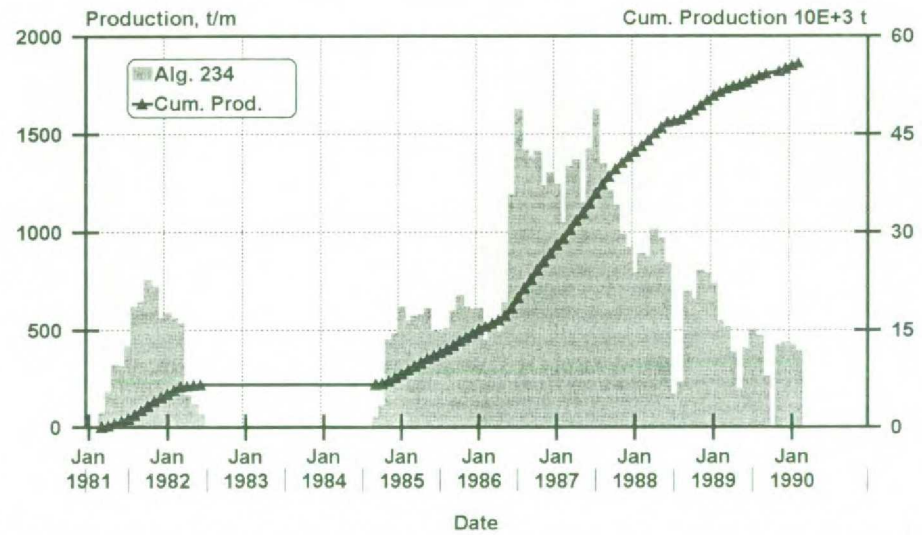

Fig. 2. Effect of "Polymer/Silicate" treatment on surplus oil production (Well Alg. 234)

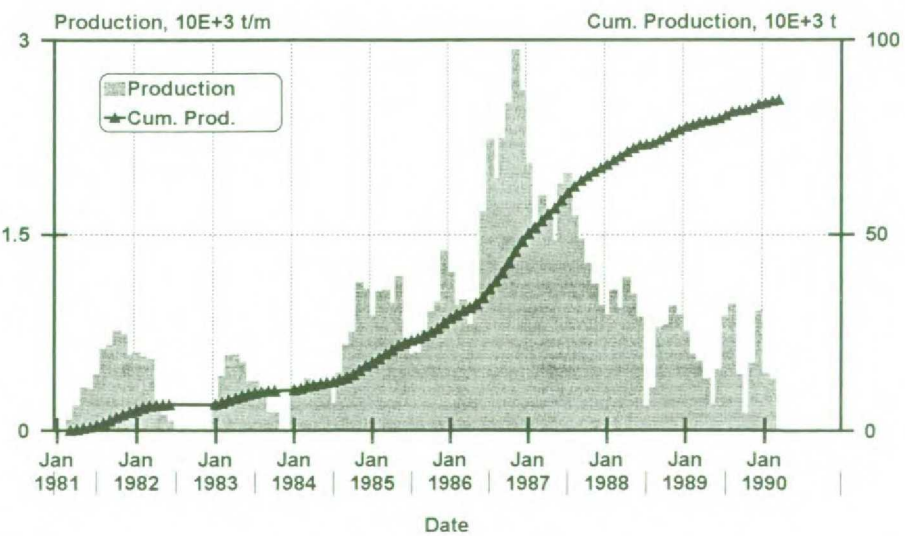

Fig. 3. Cumulative results of the "Polymer/Slicate" well treatment technique applied at the Algyő field

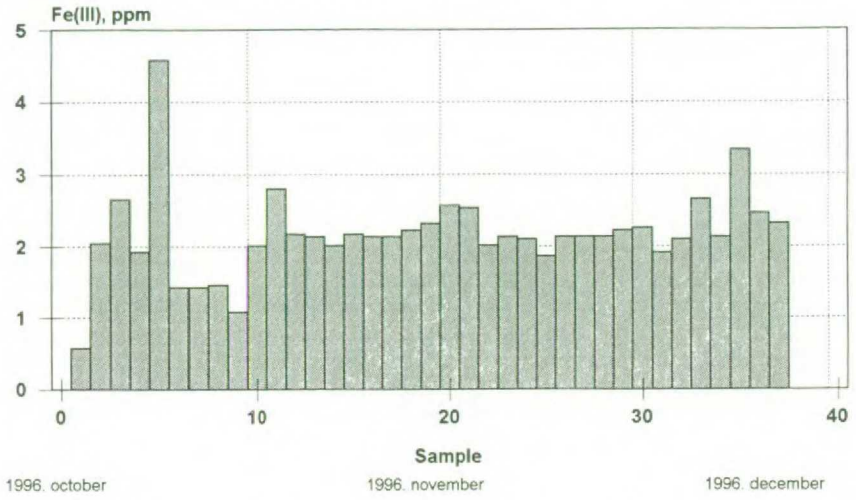

Fig. 4. Fe(III) content of water produced from Alg. 840 well after treatment

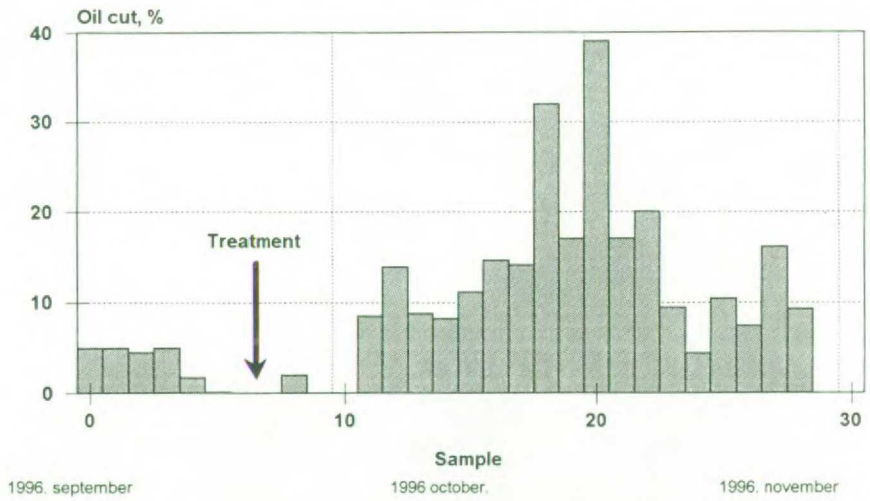

Fig. 5. Oil cut of Alg. 840 well before and after the treatment

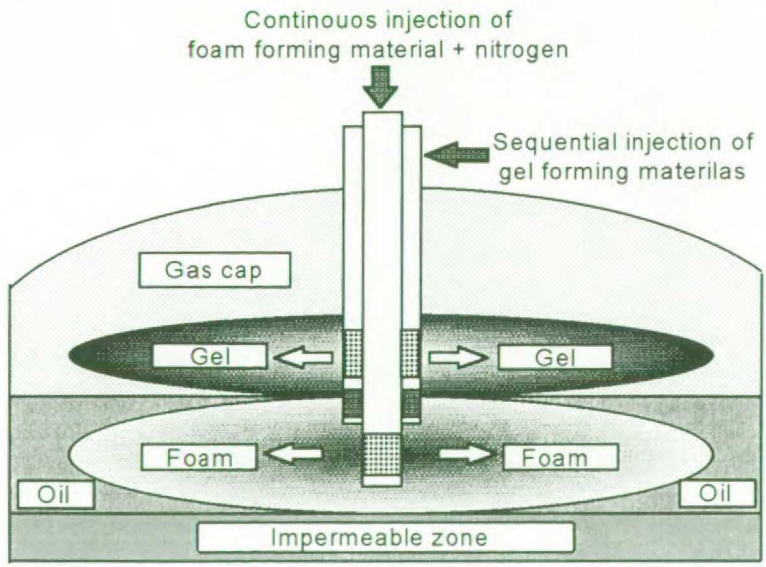

Fig. 6. Schematic of the "Foam/Gel" technique applied for restriction of gas conning