IMPROVING OIL RECOVERY IN KAZAKHSTAN OILFIELDS BY USING POLYACRYLAMIDE

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IMPROVING OIL RECOVERY IN KAZAKHSTAN OILFIELDS BY USING POLYACRYLAMIDE

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DEDICATION

In the name of Allah, Most Gracious, Most Merciful

All praise and thanks are due to Allah Almighty and peace and blessings be upon His Messenger

The results of this effort are truly dedicated to my mother and father whose example as devoted professionals, as well as, parents taught me to be perseverant, responsible and loyal to my belief.

To my family, brothers, and sisters, and my best friend for all their support, encouragement, sacrifice, and especially for their love.

Thank you all and this work is for YOU.

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ABSTRACT

This research presents a cross-linked polymer system (CPS), which is classified as a gel. Cross-linked polymers can be used in chemical enhanced oil recovery as an in-depth profile regulation agent, and at the same time as an oil dislocation agent in a heterogeneous reservoir. The cross-linked polymer gel system has comparatively low strength but it can still be cross-linked in the reservoir. The cross-linked polymer system comprises of polyacrylamide and chromium(III) acetate. The EOR mechanisms of the cross-linked polymer system are reported in detail. The effects of temperature, concentration, pH value on gelation time, rheological properties, gelation range, and gel strength were examined in this research. The Treeys-Pylot software was used in this research for simulations and efficiency prediction. The simulation results were found to have given clear evidence that the CPS succeeded in developing the injection profile which has increased the sweep efficiency. This in turn increased the oil recovery. Moreover, CPS treatment has been done in Dakes oil field in Kazakhstan since 2002. It was found that the CPS can improve oil recovery and effectively reduce water breakthrough. By the end of 2006, the cumulative oil production had been over 821,115 bbl. The predicted and real efficiency data were successfully correlated. The correction coefficient for Treeys-Pylot Software was obtained and equal to 0.85. Akbiken oilfield in Kazakhstan also has problem with water breakthrough. This research suggests using the CPS technology to solve this problem. Both oilfields are very similar, thus the obtained correction coefficient can be used for Akbiken oilfield. The efficiency can be correctly predicted using this coefficient.

ABSTRAK

Kajian ini mengetengahkan sistem polimer rangkaian silang yang dikelaskan sebagai gel. Polimer rangkaian silang boleh digunakan dalam kaedah perolehan minyak tertingkat kimia sebagai agen pengawalan profil dan pada masa yang sama sebagai agen pengalihtempatan minyak di medan heterogen. Sistem gel polimer rangkaian silang mempunyai kekuatan bandingan yang rendah tetapi masih boleh merangkai silang dalam reservoir. Komposisi teknologi CPS ialah poliakrilamida dan kromium(III) asetat. Mekanisme EOR bagi sistem polimer rangkaian silang dilaporkan secara terperinci. Kesan suhu, kepekatan, nilai pH terhadap masa penggelan, sifat reologi, julat penggelan dan kekuatan gel telah dikaji dalam penyelidikan ini. Perisian Treeys-Pylot digunakan dalam penyelidikan ini untuk melakukan simulasi dan meramal kecekapan. Keputusan simulasi membuktikan bahawa CPS berjaya membangunkan profil suntikan yang berjaya meningkatkan kecekapan sapuan dan seterusnya meningkatkan perolehan minyak. Ujian perintis dilakukan di medan minyak Dakes di Kazakhstan semenjak tahun 2002. CPS didapati berjaya meningkatkan perolehan minyak dan mengurangkan penerobosan air. Pada akhir tahun 2006, pengeluaran kumulatif minyak ialah melebihi 821,115 tong. Data ramalan dan kecekapan sebenar berjaya disekaitkan. Pekali pembetulan bagi perisian Treeys-Pylot yang berjaya diperoleh ialah 0.85. Penerobosan air ialah masalah teknikal yang dihadapi oleh medan minyak Akbiken di Kazakhstan. Penyelidikan ini mencadangkan penggunaan teknologi CPS untuk menyelesaikan masalah ini. Kedua-dua medan minyak adalah serupa. Oleh itu, pekali pembetulan boleh digunakan untuk medan minyak Akbiken. Kecekapannya boleh diramalkan dengan betul menggunakan pekali ini.

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LIST OF ABBREVIATIONS

API	American Petroleum Institute
bbl	Barrel
BOPD	Barrels Oil per Day
CPS	Cross-linked Polymer System
CSE	Cellulose sulphate ester
EOR	Enhanced Oil Recovery
etc	et cetera, a Latin expression meaning "and other things"
HEC	Hydroxyethyl cellulose
HPAM	Hydrolyzed Polyacrylamide
IOR	Increased Oil Recovery
MSTB	Thousand(s) Stock Tank Barrels
MMSTB	Million Stock Tank Barrels
OWC	Oil Water Contact
OIIP	Oil Initially In Place
OIP	Oil In Place
PAA	Polyacrylamide
ppm	Part per million
PV	Pore Volume
PVP	Polyvinylpyrrolidone
RMS	Root-mean-square
STB/D	Stock Tank Barrels per Day
t/d	Tonne Per Day (Matric)
WOR	Water Oil Ratio
US$	American Dollar

LIST OF NOMENCLATURES

SYMBOL	DEFINITION
M	Mobility ratio, fraction
λ_w	Water mobility, fraction
λ_o	Oil mobility, fraction
K_{rw}	Water relative permeability, fraction
K_{ro}	Oil relative permeability, fraction
μ_o	Oil viscosity, cp
μ_w	Water viscosity, cp
q_w	Water flow rate, m^3/day
q_o	Oil flow rate, m^3/day
$\overline{S_w}$	Average water saturation behind the flood front, fraction
E	Total efficiency factor, fraction
E_V	Volumetric sweep efficiency, fraction
E_D	Displacement efficiency, fraction
E_{AS}	Areal Sweep Efficiency, fraction
E_{Vs}	Vertical Sweep Efficiency, fraction
C_p	Polymer concentration in solution, kg/m^3
a_4	Constant parameter which is a function of salinity, fraction
b_4	Constant parameter which controls curvature of the isotherm, fraction
S_{dpv}	Dead pore space within each grid cell, fraction
C_a	Polymer adsorption, kg/kg

ρ_r	Mass density of the rock formation, m^3/ kg
ϕ	Porosity, fraction
ρ_w	Water density, m^3/ kg
ρ_o	Oil density, m^3/ kg
R_k	Relative permeability reduction factor for the aqueous phase, fraction
C_n	Sodium chloride concentration in the aqueous phase, kg/m^3
μ_{weff}	Effective viscosity of the water, cp
$\mu_{p\,eff}$	Effective viscosity of the polymer, cp
$\mu_{s\,eff}$	Effective viscosity of the salt, cp
B	Denotes the formation volume factor of rock, oil and water, fraction
V	Denotes the pore volume in the grid cell, m^3
T	Transmissibility, fraction
Dz	Depth difference, meter
S_w^*	Saturation of polymer solution, fraction
S_w	Saturation of whole aqueous phase, fraction
ω	Todd-Longstaff mixing parameter, fraction
$\overline{C}$	Effective saturation for the injected polymer solution, fraction
B_w	Water formation volume factor, fraction
B_o	Oil formation volume factor, fraction
A'	Flow area between two cells, m^2
F_m	Viscosity multiplier assuming no shear effect, fraction
F_r	Shear thinning multiplier supplied, fraction
ϕ_{avg}	Average porosity of the two cells, fraction
P_o	Reservoir pressure in oil bank, psia
P_w	Reservoir pressure in water bank, psia
A	Cross sectional area, acre
K	Absolute permeability, darcy
L	Length , feet

f_w	Fraction of flowing fluid consisting of water, fraction
S_{or}	Residual oil saturation, fraction
S_{wi}	Initial water saturation, fraction
S_{wf}	Water saturation at the flood front, fraction
$Ave\ S_w$	Average water saturation, fraction
S_o	Oil saturation, fraction
$\mu_m(\mathrm{C}_p)$	Viscosity of polymer in the solution, cp
μ_p	Viscosity of injected polymer, cp
$c_{p,\max}$	Maximum polymer concentration, kg/kg
$\mu_{w,e}$	Partially mixed water viscosity, cp
$C_{a\max}$	Maximum adsorbed concentration, kg/kg
RRF	Residual resistance factor, fraction
Q_w	Water injection rate, m^3/day

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CHAPTER 1

INTRODUCTION

1.1 Background

Natural reservoir energy or primary methods force oil to producing wells. Over time these natural energies drop. As a result, the primary methods (gas cap drive, liquid and rock expansion drive, solution gas drive, natural water influx, and combination of these methods) extract only 30% to 40% of oil. In general, natural drive mechanisms leave behind about 60% to 70% of the initial oil in place. Traditionally oil production strategies have followed primary depletion, secondary recovery and tertiary recovery processes (Fig.1.1) (Willhite et al., 2000).

Primary depletion, also refers to as primary production, uses the natural reservoir energy to accomplish the displacement of oil from the porous rocks to the producing wells (Craft et al., 1991). As a general rule, it is expected that one third of the original oil in place can be recovered by primary methods. In the oil industry waterflooding is being widely used like the secondary method, because it is a simple and low-cost method.

But this method has some problems. A number of waterflood failures reported in the survey were caused by adverse permeability variations, which resulted in rapid water breakthrough and high water production. While a number of these projects were in older fields where core analyses were unavailable, many were in areas where zones of high permeability were known to exist (Burcik, 1969).

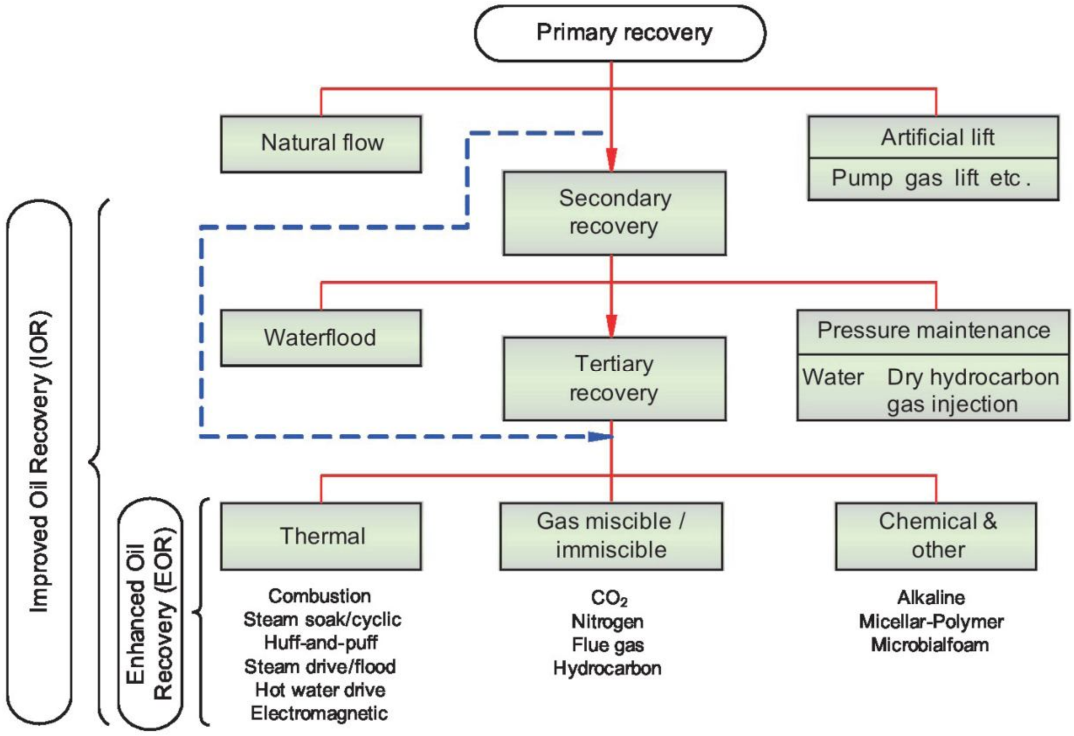

Figure 1.1 Summary of recovery methods and their relationship to field development

Fig. 1.2 is a simplified drawing showing a zone of high permeability (k1) at the top of a formation. Water following the path of least resistance has a tendency to enter only this zone, resulting in early breakthrough with a considerable amount of oil remaining in the reservoir. Total sweep efficiency is defined as the product of the areal and vertical sweep efficiencies. Therefore, even though a project may have a high areal sweep, it may be offset by a low vertical efficiency which is a function of permeability variation. This factor is often ignored and a recovery factor which is much too high is used to calculate the recoverable oil (Burcik, 1969).

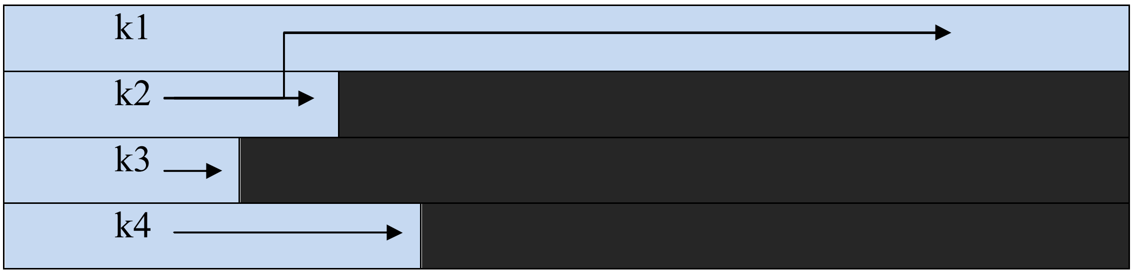

Figure 1.2 Zone of high permeability at the top of a formation

Figure 1.3 Map of Kazakhstan and Akbiken oilfield's location

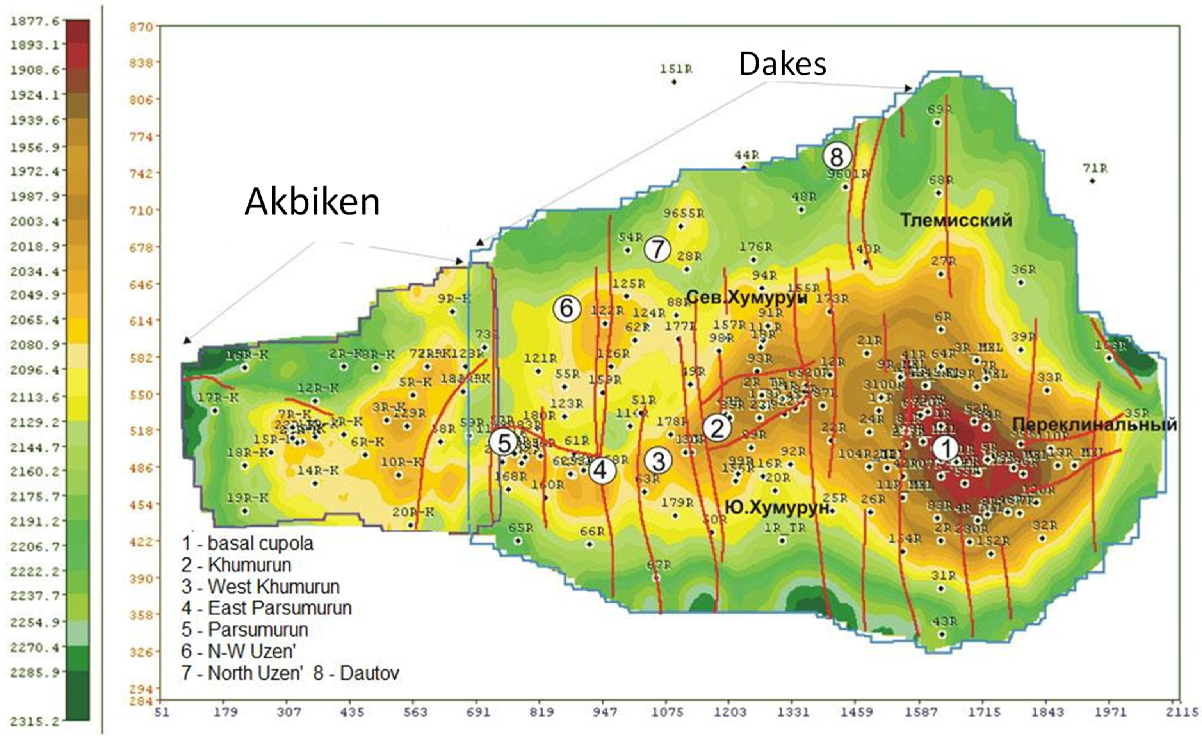

Figure 1.4 Structural map of Akbiken and Dakes oilfields

Akbiken oilfield (Fig. 1.3) is located in the West Kazakhstan, 160 km from Aktau city. This oilfield is a continuation of Dakes oilfield (Fig. 1.4). The oilfield was opened in 1964 and production started from 1973. Initial crude oil reserves are estimated to be 452 mln. bbl. Recoverable reserves are about 144 mln. bbl. The oil recovery factor is 0.43. Cumulative oil production is 75 mln. bbl. The area of Akbiken oilfield is about 30 km^2 (Kulsariev and Mustafaev, 2005).

The problems of Akbiken oilfield are:

1. High excavation of high productivity oil deposits.
2. Water breakthrough in high permeable zones.
3. Involved in the development of oil deposits with hard recoverable reserves. These low permeability oil deposits are difficult to produce.
4. Renewal permeability of bottomhole formation zones.

The production company uses several EOR methods in Akbiken and Dakes oilfields (Dzhandosov, 2007). The methods are:

1. Depression perforation
2. Heat chemical treatment
3. Reservoir fracturing
4. Cross-linked polymer systems (only for Dakes oilfield)
5. Repair-and-isolation operations
6. Polymer-and-gel makeup
7. Electrical effect

The use of polymeric systems for profile modification or plugging is increasing. Currently, cement or mechanical systems are the widely used methods for permanently controlling water flow. However, cement and mechanical methods are effective only in the well bore area. In reservoirs with good vertical permeability and no intervening shales, these profile control methods are not successful. Cement's greatest disadvantage is that it cannot penetrate the formation matrix, so its effect is limited to within the drilled hole (Cosse, 1993).

There are three types of water control problems in water flooding systems:

1. Open flow paths-this kind of problems is associated with the presence of fissures, fractures or faults or to oil being confined to the rock matrix.
2. Fluid fingering or viscous fingering (edge water) is caused by post aerial sweep which is common in heterogeneous reservoir.
3. Conning water or bottom water problem- where oil is being produced near the oil water contextures. Thus, too much water is also being produced.

All three problems can be handled by CPS injection to eliminate or minimize the effects. In the last seven years, Production Company of Dakes oilfield uses a combination of waterflooding and polymers (CPS). This combination helps to solve problems with sweep efficiency, mobility ratio, and redistribution of injected water vertically and horizontally. Polymer flooding can yield significant increase in percentage recovery when compared to conventional water flood projects in certain reservoirs. The addition of a polymer yields two benefits 1) reduces the total volume of water required to reach the ultimate residual oil saturation and 2) increases sweep efficiency due to improved mobility ratio. Many successful projects have reported increased recoveries of 5-15%. Many unprofitable projects were the result of inadequate reservoir description or problems with the polymer system being used. In recent years the polymer gel flooding technology has been field tested extensively and can be classified as proven technology (Fulin et al., 2006).

The Kazakhstan economy is highly dependent on crude oil resources at a reasonable price. As the exploration and production of crude oil approaches its inevitable peak, Kazakhstan has no other choice but to look for secure and reliable new crude oil resources. The best source of securing the required oil resources are the billions of barrels of oil left behind in the Kazakhstan waiting for a cost effective technology to bring them up. As a vital means of tertiary oil recovery, CPS injection is indeed superior to all other known methods of enhancing oil recovery today. It is the cheapest, efficient, and practical provided it will work in every type of reservoir rock and structure. It requires minimal initial capital for operation and maintenance, it will not interfere with day to day normal field production operation, and it will receive the highest tax credit (Dzhandosov, 2007).

1.2 Research Objectives

This research is aimed to improve the oil recovery factor of Akbiken oilfield (Kazakhstan). In doing so, this study attempts to investigate some of the issues raised in the previous section. The specific objectives are divided into three parts.

The first part of this research focused on CPS properties. The EOR mechanisms of the cross-linked polymer system are reported in detail. Effects of temperature, concentration, pH value on gelation time, the rheological property, gelation range, and gel strength are investigated by experiments.

The second part of this research focused on Dakes oilfield. First of all, the data were generated and collected. Secondly, actual production data and software prediction data were correlated. Thus, the correction coefficient was derived for correction the predicted production data after simulation in Akbiken oilfield.

The third part of this research focused on Akbiken oilfield. Oil recovery for this oilfield was predicted by using the above findings. Profitability of CPS technology was calculated.

1.3 Research Scopes

This research will be conducted to focus on the CPS (cross-linked polymer system) flooding. During this research experiments, simulation, and prediction methods will be used to show CPS injection results. Oilfields simulation and prediction results of using CPS technology would be carried out by Treeys-Pylot software.

The novelty of this research is the correlation of actual production results and predicted results. Thus, accuracy of the computer software is verified and the correction coefficient is derived. Using the above findings, oil recovery prediction for another oilfield will be more accurate and useful.

The scopes are divided into two parts. First part focused on Dakes oilfield. The scopes of this part are:

1. Analyzing efficiency of using cross-linked polymer flooding in Dakes oilfield.
2. Modeling Dakes oilfield for cross-linked polymer flooding simulation by Treeys-Pylot software.
3. Comparing real results of using CPS and prediction results of Treeys-Pylot software.
4. Explaining reasons of success or failure of prediction.
5. Derivation of the correction coefficient for Treeys-Pylot software.

Second part is focused on Akbiken oilfield. The scopes of this part are:

1. Prediction effects of using CPS in Akbiken oilfield, based on results of using CPS in Dakes oilfield.
2. Prediction of economical effect of using CPS in Akbiken oilfield.

1.4 Limitations

Main point of this research is CPS technology simulation. For more accurate results, gel movement process in the layers must be known. Therefore, all experiments in this research will be done only for understanding CPS gel movement processes.

During this research CPS technology will be analyzed. Physical and mobility properties of injected gel will be developed by experiments. These knowledge are necessary for clear understanding of the gel movement in the layers and for the more accurate simulation.

Dakes oilfield is very large. Well stock of this oilfield is 6,219 wells. Dakes oilfield is a large anticline structure, sized 39 km by 9 km, having exclusively complicated geological structure. Simulation of CPS technology for all horizons of Dakes oilfield is very complicated and needs too much time. Therefore, modelling and simulation will be done only for the two from thirteen horizons of Dakes oilfield.