SIMULATION STUDY OF IMPROVING OIL RECOVERY BY POLYMER FLOODING IN A MALAYSIAN RESERVOIR

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ABSTRACT

This research is a simulation study to improve oil recovery using waterflooding and polymer flooding techniques based on data obtained from the Perdana oilfield in Malaysia and the Brillig reservoir as described in Eclipse 2000. There was no published report on polymer flooding project or polymer flooding simulation work that has been carried out for the Perdana oilfield. These two simulation studies have illustrated the feasibility of polymer flooding and provided the technical knowledge that can be used to study other techniques of improved oil recovery (IOR) to be implemented in Malaysian oilfields. Use of polymer increases water viscosity which controls water mobility thus improving the sweep efficiency. The simulations were carried out using the black oil model. In the simulation, factors such as polymer shear thinning effect, adsorption, concentration, permeability reduction, and fluid viscosity have been taken into account when constructing the mathematical model. For the Perdana reservoir, the polymer slug size was 0.624 PV, polymer concentration was 2500 ppm, oil recovery was 48%, and the incremental oil recovery was about 11%. For Brillig reservoir, the polymer slug size was 1.11 PV, polymer concentration was 2000 ppm, oil recovery was 45%, and the incremental oil recovery was about 8%. The waterflooding and polymer flooding costs were also studied for both methods in the Perdana reservoir. The polymer flooding project in this study has shown a better outcome compared to waterflooding project. The total production costs for a single barrel via polymer flooding and waterflooding were US$9.57 and US$5.68 respectively. Following that, the forecasted net profits of polymer flooding and water flooding for the Perdana oil field were US$2.04 billion and US$1.65 billion respectively, and the profit from the polymer flooding project over waterflooding project was US$390 million.

ABSTRAK

Penyelidikan ini merupakan kajian simulasi bagi mempertingkat perolehan minyak menggunakan teknik banjiran air dan banjiran polimer. Data diperoleh daripada lapangan minyak Perdana di Malaysia dan reservoir minyak Brillig dalam Eclipse 2000. Sehingga kini, tiada sebarang bahan tertbitan tentang projek banjiran polimer mahupun kerja simulasi banjiran polimer di lapangan minyak Perdana. Kajian ini menunjukkan bahawa terdapat kemungkinan penggunaan banjiran polimer dalam peningkatan perolehan minyak (IOR) dan menyumbang kepada bidang teknikal yang boleh digunakan dalam kajian teknik lain untuk meningkatan perolehan minyak di Malaysia. Penggunaan polimer dapat menambah kelikatan air serta mengawal pergerakannya di samping meningkatkan daya aliran. Simulasi dilaksana menggunakan model minyak hitam. Faktor-faktor dalam polimer, misalnya kesan kericihan, daya serapan, kepekatan, pengurangan ketertelapan, dan kelikatan bendalir telah diambil kira dalam menerbitkan model matematik. Reservior minyak Perdana yang dikenakan slug polimer berukuran 0.624 PV dengan kepekatan 2500 ppm berjaya menghasilkan perolehan minyak sebanyak 48% dan menunjukkan peningkatan sebanyak 11%. Bagi reservoir minyak Brillig yang menggunakan slug polimer bersaiz 1.11 PV dengan kepekatan polimer 2000 ppm, perolehan minyaknya 45% dengan peningkatan sebanyak 8%. Kos pengendalian banjiran air dan banjiran polimer terhadap reservoir minyak Perdana turut dikaji. Hasil menunjukkan bahawa projek banjiran polimer memberi pulangan yang lebih baik berbanding projek banjiran air. Jumlah kos pengeluaran bagi setiap tong menggunakan teknik banjiran polimer ialah US$9.57 manakala teknik banjiran air pula adalah lebih kurang US$5.68. Anggaran keuntungan yang bakal diperoleh daripada lapangan minyak Perdana ialah US$2.04 bilion bila menggunakan teknik banjiran polimer, manakala US$1.65 bilion untuk teknik banjiran air. Oleh yang demikian, keuntungan projek yang menggunakan teknik banjiran polimer aberbanding teknik banjiran air ialah US$390 juta.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Background

About 85% of world energy demand is delivered by fossil energy and oil's share in world demand is more than 30%[1]. World oil consumption per year has increased from 3.2 billion m^3 in 1975 to 4.4 billion m^3 in 2000 and which is expected to increase up to 5.2 billion m^3 in 2010. The last decade has seen a progressive increase in global discovery volumes of oil. This is mainly due to two reasons which are: access to some very prospective resource areas and advances in technology[1]. Every oil reservoir, whether mature, recent or yet to be discovered, is a candidate for enhanced oil recovery (EOR). This is because reservoirs still contain significant quantities of oil after conventional primary and secondary recovery operations. Conversion of candidates into projects is a function of economic climate, available technology, and operator priorities. Oil production strategies have followed primary depletion, secondary recovery and tertiary recovery processes. All these methods are typically used one after another in the development of an oilfield, and the transition between methods occurs when a production method becomes uneconomic. This strategy in the production of oil is not necessarily efficient, although it is convenient from a planning standpoint. In many cases, the use of tertiary methods without the use of secondary methods could improve the overall recovery of the field after primary depletion.

Displacement methods require the movement of a volume of injected fluid and reservoir fluid from one part of the reservoir to another. If enough information is available petroleum engineers are able to approximate or simulate reservoir conditions through computer modeling so that they have some idea of what might work best[2]. However, it is not possible to exactly simulate any given natural reservoir because of the tremendous number of variable parameters. Primary depletion refers to as primary production, uses the natural reservoir energy to accomplish the displacement of oil from the porous rocks towards production wells. Natural reservoir energy or primary methods force oil to producer wells with a consequent drop in the reservoir pressure. The reservoir pressure would drop below the bubble point pressure, and the dissolved gas would be released from the oil.

Primary methods extract only about 30% to 40% of the original oil in place. In general, natural drive mechanisms leave behind about 60% to 70% of the oil initial in place. To maintain reservoir pressure and also to sweep out oil in more efficient displacement process waterflooding is being widely used in many reservoir formations as a simple inexpensive secondary method. The secondary methods augment natural energy by fluid injection (gas, water and gas waterflooding) as shown in Figure 1.1. The waterflooding has been reviewed in some details, the inefficient displacement by waterflood mechanism is mainly due to unfavorable mobility ratio or reservoir heterogeneity[3,4]. For these reasons, the production plan should include chemical enhanced oil recovery (EOR) processes as tertiary methods to recover the otherwise irrecoverable oil in the reservoir rock. A fact has been established that the mobility of the brine used in waterflooding was greatly reduced by the addition of very small amounts of hydrolyzed polyacrylamide, a water-soluble polymer. This reduction in brine mobility resulted in greater oil recovery than that attributable to conventional water flooding[5].

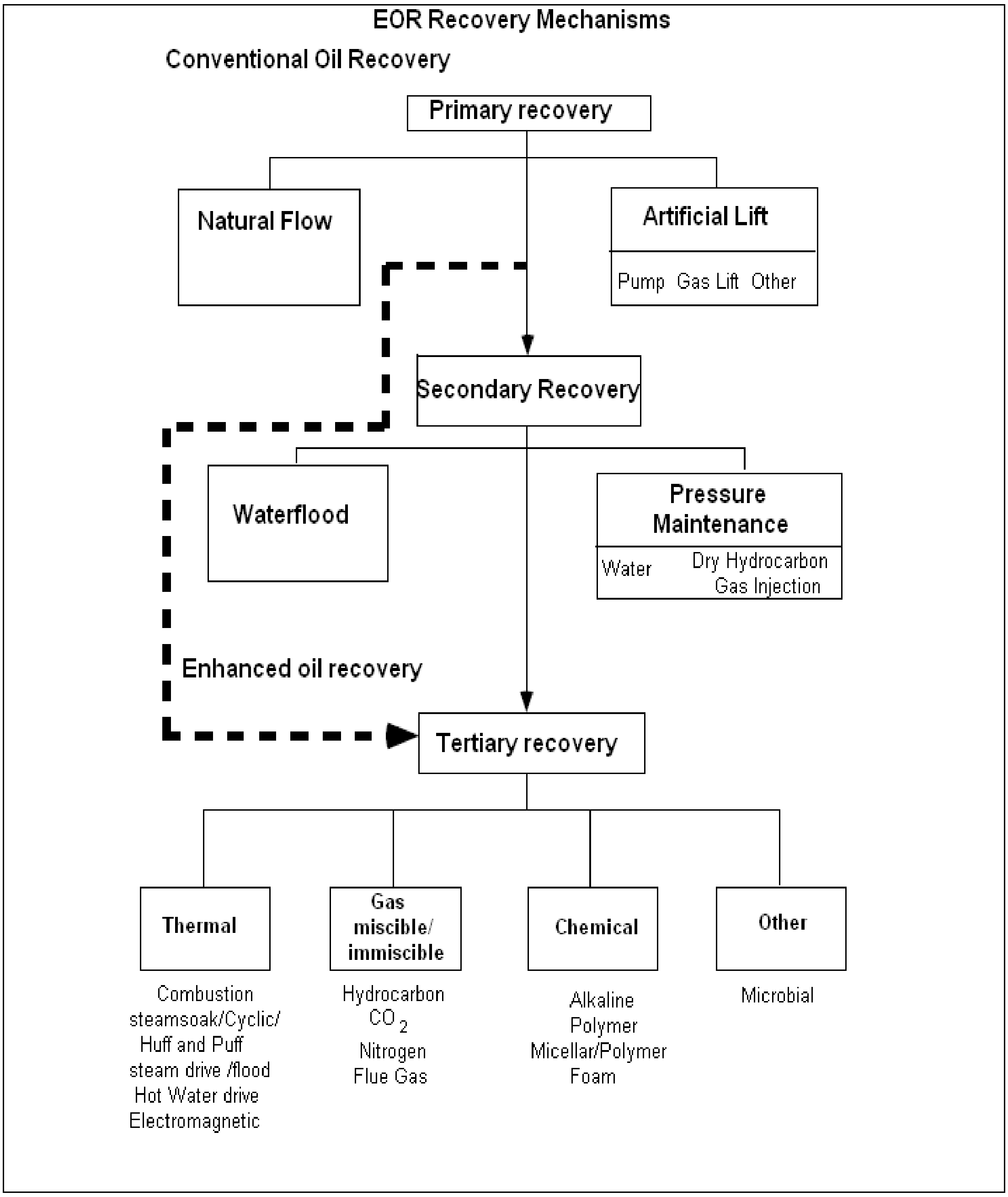

Figure 1.1 Summary of recovery methods.

Many additional papers sustaining and extending this information have since appeared in the literature. Some field information has been provided about the most suitable reservoir and fluid characteristics for polymer flooding applications [6]. The purpose of their paper is to present basic conditions and test results for a large number of polymer flood projects and to examine the ranges of some of the more important parameters within which success has been achieved. In addition, the effects of variations in several important reservoir and polymer properties upon polymer flood recovery are illustrated with the aid of a computer program. Such effects were not readily observable by field testing.

1.2 Simulation Work

Simulation work has been used for predicting and optimizing reservoir performance since the beginning of petroleum industry. Initial studies were composed of laboratory models and analytical calculation. In the early sixties, the term simulation was commonly used for predictive methods that use relatively sophisticated computer programs. These programs were the solutions of the equations that govern rnultiphase fluid flow in porous media using finite difference techniques. The advancement in computer technology together with the development of numerical methods for solving finite difference equations resulted in the capability to solve large sets of equations describing multiphase flow in multi-dimensions, anisotropic, heterogeneous media. For the most part the problems attempted were two phase gas/water or gas/oil and three-phase systems. In the early seventies, due to increased demands for energy enhanced recovery techniques gained importance thus the necessity of simulating complex systems and processes led to the development of new models like chemical flooding, miscible fluid injection, steam or hot water injection, polymer flooding, and enriched gas injection. In general these models, according to their nature of formulation and capabilities, can be grouped into four categories namely, black-oil, compositional, thermal, and chemical [7].

The numerical method proposed by Douglas, Blair, and Wagner was significant. For the first time, capillary pressure was taken into account mathematically[8].The differential equation governing the displacement process in a linear and homogeneous reservoir was transformed to a difference equation and solved numerically. The results have been offered of a two dimensional mathematical model that included the effects of relative permeabilities, fluid viscosities, densities, and gravity and capillary pressure. Thus, it included all the necessary fluid flow effects and considered two dimensional well pattern effects[9].

Two-phase multilayer of Buckley-Leverett displacement has been developed, the simulator capable of modeling either linear or five-spot patterns[6]. Mobile gas saturation also could be specified, but this was treated as void space and did not affect the flow characteristics of the system. Gravitational and capillarity effects were neglected. The residual resistance of the brine following a water slug was modeled as an increase in its viscosity. The viscous fingering of the brine through the polymer slug was treated by altering empirical relative permeability relationships to specify a more adverse mobility ratio.

1.3 Polymer Flow in Porous Media

Pye has reported that the viscosity of a polymer solution is markedly higher when the solution flows through a porous medium, than in a standard laboratory viscometer[10]. This departure is due to the polymer solution viscosity being affected by a different shear rate compared to the viscometer. The polymer causes reduction of the permeability of the porous media. Burcik and Walrond have proposed that a microgel structure in the polymer solutions may account for the mobility control[11], the permeability reduction comes by the adsorption and entrapment of the polymer particles within the pore openings[12]. Having flowed brine, polymer solution, and again brine through a sintered glass disc, and having noticed that the final brine flow rate was substantially less than the original, he flowed distilled water, and the result was a nearly plugged core. But, when the distilled water was displaced with ethyl alcohol, the mobility of the alcohol, after correction for viscosity difference, was identical to the initial brine mobility. This was probably due to the large decrease in the polymer particle size by dehydration, that is, removal of the water with alcohol, nearly restoring the initial rock permeability. Upon flushing the alcohol with distilled water, the core was again nearly plugged, indicating the presence of polymer molecules within the porous medium. Similar results have been obtained with natural, consolidated cores that were washed in HCl solution and muffled at 1500°F. Thus, once hydrolyzed polyacrylamide solution has flowed through the porous medium, the original permeability of the medium is not restored by flushing with water.

The flow behavior of partially hydrolyzed polyacrylamides in Berea sandstone, reported a distinct influence of both the molecular weight and the velocity of flow on the mobility and the residual permeability loss in porous medium. At the velocities of about 10 feet per day and greater, it was found that the mobility of the polymer solutions decreased with increasing flow rate[13].

Chemical Enhanced Oil Recovery (EOR) processes are now being considered for large scale field applications given the recent high price of crude oil. Malaysian oil fields are located offshore. This simulation study undertaken is to investigate the feasibility of increasing oil recovery through polymer flooding for oil fields in Malaysia. Polymer has been used to increase oil recovery efficiency in water injection since the mid-1960s. Experts soon realized that in addition to imparting viscosity to injected water, polymer adsorbs onto rock. Polymer is added to the water flood (water-soluble polymer), and the main objective of polymer injection during waterflooding of oil reservoirs is to decrease the mobility of the injected water.

Certain plugging effects within highly permeable layers may also occur and result in the diversion of the injected water into less permeable zones of the reservoir. The mobility decrease of the injected water resulting from the addition of polymer is due to two effects. Firstly, the viscosity of the polymer solution is higher than that of pure water (the viscosity of the polymer solution increases as the concentration of the polymer in the water increases). Secondly, the rock permeability to water is reduced after the passage of a polymer solution through the rock material. Both effects combine to reduce the value of the water mobility while that for the oil is unaltered. The results are more uniform flood front, improved waterflood efficiency, more oil produced at a lower water-oil ratio (WOR) and a more favorable fractional flow curve for the injected water leading to a more efficient sweep pattern and reduced viscous fingering.

To achieve maximum efficiency, the polymer solution is often applied in the form of a tapered slug. At the front edge of the slug, the displacement is stable but the interface between the water and the polymer solution smears due to physical dispersion of the polymer. At the rear edge, the mobility ratio is unfavorable and is dominated by viscous fingering. Both effects cause deterioration of the slug, and are modeled in Eclipse by means of a mixing parameter applied to the viscosity terms in the fluid flow equations.

1.4 Problem Statement

When petroleum reservoirs are depleted by natural drive mechanisms due to decreasing reservoir pressure only a small fraction of the oil can be produced (30-40%). Implementing a secondary recovery, waterflooding, would still not produce all the recoverable oil present in the reservoir. At the time of breakthrough the water cut level is high. The inefficiency of recovery is coupled by the fact that some regions in the reservoir, such as having low permeability sands, will not be swept by the injected water at all. The factor of high water mobility ratio results in poor volumetric sweep efficiency especially when reservoir rock is highly heterogeneous.

Under the current scenario of highly escalating oil price, it would be economically sound to eke out more barrels from the presently producing fields by implementing an IOR. One of the methods to be looked into would be polymer flooding which augments waterflooding with greater recovery through the addition of polymer solution to enhance mobility ratio of the flood.

To date, no polymer flooding had been implemented on any Malaysian oil fields even though waterflooding is common. No reported simulation work has been published for this oil recovery technique for Perdana oil field.

A simulation study of a polymer flooding process for a Malaysian oilfield should thus be undertaken in order to indicate if the proposed IOR is technically feasible, and economically attractive.

1.5 Objective

The objectives of this research are:

i- To investigate the effectiveness of water flood and polymer flood projects in Perdana reservoir located in Malaysian offshore and Brillig reservoir a reservoir described by Eclipse 2000.

ii- To model the Perdana reservoir and Brillig reservoir for the purpose of polymer flooding simulation runs

iii- To simulate the process using Eclipse 2000 thus enabling analysis of the process as undertaken by many known field operators

iv- To fully understand the complexity of the process, the important factors influencing oil recovery of the polymer flood would be studied for Perdana Reservoir. Similar runs would be made on Brillig reservoir as well, and the results of the runs for both fields would be discussed.

v- To investigate oil and water production rate.

vi- To investigate water cut levels.

vii- To investigate cumulative oil and water production.

viii- To investigate reservoir production for history matching.

ix- To investigate recovery factor.

1.6 Scope

This research will be carried out to focus on the oil recovery methods with use of secondary recovery methods and tertiary recovery methods which will improve oil recovery. Water injection is the oldest conventional recovery method used after primary recovery which is a successful engineering technique in heterogeneity reservoirs to displace crude oil to production wells. Reservoir simulation studies of water flood and polymer flood model into Perdana reservoir and Brillig reservoir that would be carried out using Eclipse 2000 simulation. The scopes of this research as follows:

i- To study effectiveness of the following parameters on oil recovery factor when modelled and run on Eclipse:

1. Polymer adsorption
2. Polymer concentration
3. Polymer solution viscosity
4. Mobility ratio
5. Fractional flow curve
6. Residual oil saturation
7. Displacement efficiency
8. Reservoir water salinity
9. Injection time
10. Slug size
11. Vertical permeability to horizontal permeability ratio (K_v/K_h)

ii- To select a polymer slug size that gives the best economic return

iii- To study the economic aspect of polymer flooding economic (costing) for the cases run

REFERENCES

1. Jerome, K. F. (2003). *Flow of Polymer Solutions through Porous Media.* An imprint of Delft University Press: Published and distributed by: DUP Science.
2. Klehs, J., Andal, F. D., Parrish, C., Chiang, J. and Connell, K. (1996). *Assessment of Petroleum Properties.* Taxes, California: State Board of Equalization Handbook Section 566.
3. Craig, F. F., Jr. (1971). *The Reservoir Engineering Aspect of Water Flooding*. Monograph Series. Dallas, Taxes: Society of Petroleum Engineers.
4. Willhite, G. P. (1986). *Waterflooding*. Seventh Printing. Richardson, Taxes: Society of Petroleum Engineers. Textbook Series Volume, 3: 1-7.
5. Sandiford, B. B. (1964). Laboratory and Field Studies of Water Floods Using Polymer Solutions to Increase Oil Recoveries. *J. Pet. Tech*. Trans. AIME. 231: 917-922.
6. Jewett, R. L. and Schurz, G. F. (1970). Polymer Flooding - A Current Appraisal. *J. Pet. Tch*. Preprint 2545: 675-684.
7. Bilgesu, H. I. and Ertekin, T. (1985). Development of a Multipurpose Numerical Model. *Eastern Regional Meeting.* November 6-8. Morgantown, West Virginia: SPE 14521, 299- 310.
8. Douglas, J., Blair, P. M., and Wagner, R. J. (1958). Calculation of linear waterflood behavior including the effects of capillary pressure. *Trans. AIME*. 213: 96-102.
9. Douglas, J., Peaceman, D. W., and Rachford, H. H. (1959). A Method For Calculating Multi-Dimensional Immiscible Displacement. *Trans. AIME*. 216: 297-308.
10. Pye, D. J. (1964). Improved Secondary Recovery by Control of Water Mobility. *J. Pet. Tech.* Trans. ATME 231: 911- 916.

11. Burcik, E. J. and Walrond, K. W. (1968). Microgel in polyacrylamide solutions and its role in mobility control. *Pord. Monthly*. 32: 12.

12. Burcik (1965). A note on the flow behaviour of polyacrylamide solutions in porous media. *Pord. Monthly*. 29: 14.

13. Smith, F. W. (1970). The behaviour of partially hydrolysed polyacrylamide solutions in porous media. *J. Pet. Tech*. 22: 148- 156.

14. Knight B. L. and Rhudy, J. S. (1977). Recovery of high viscosity crudes by polymer flooding. *The 26th Annual Technical Meeting*. June 11-13. Banff, Canada: J. Can. Pet. Tech, 46-56.

15. Welge, H. J. (1952). A simplified Method for Computing Oil Recovery by Gas or Water Drive. *Trans. AIME*. 195: 39- 46.

16. Zapata V. J. and Lake L. W. (1981). A Theoretical Analysis of Viscous Crossflow. *the 56th Annual Fall Technical Conference and Exhibition of the society of Petroleum Engineers of AIME*. October 5-7. San Antonio, Texas: SPE 10111, 2-5.

17. Patton J. T., Coats, K. H., and Colegrove, G. T. (1969). Prediction of Polymer Flood Performance.*The SPE 44th Annual Fall Meeting.* Sept. 28 - Oct. 1. Denver, Colo: SPE 2546. 72-84.

18. Craft B. C., Hawkins M. F. and Terry R. E. (1991). *Applied Petroleum Reservoir Engineering*. Second Edition. Englewood Cliffs, N. J: Prentice Hall PTR 4-6. 376-384.

19. Neil, J. D., Chang, H. L. and Geffen T. M. (1983). Waterflooding and Improved Waterflooding. In: *Improved Oil Recovery*. Oklahoma City. Interstate Oil Compact Commission. 1-52.

20. Muskat, M. (1949). *Physical Principles of Oil Production*. New York: McGraw-Hill Book Co.

21. Ahmad, T. (2000). *Reservoir Engineering Handbook.* Second Edition. Houston, Texas: Gulf Publishing Company.

22. Shupe, R. D. (1981). Chemical Stability of Polyacrylamide Polymers. *Journal of Petroleum Technology,* (33): 1513-1529.

23. Mungan, N., Smith, F. W. and Thompson, J. L. (1966). Some aspects of polymer floods. *J. Pet. Tech. Trans.* AIME, 237: 1143-1150.

24. Gogarty, W. B. (1967). Mobility control with polymer solutions. *Soc. Pet. Eng. J. Trans.* AIME, 240: 161- 170.

25. Green, D. W., and Willhite, G. P. (1998). *Enhanced Oil Recovery*. Richardson, Taxis: Society of Petroleum Engineers. SPE Textbook Series Vol. 6. 100-113.

26. Maerker, J. M. (1973). Dependence of polymer retention on flow rate. *J. Pet. Tech*. 25: 1307-1308.

27. Seright (1980). The Effects of Mechanical Degradation And Viscoelastic Behaviour on Injectivity of Polyacrylamide Solutions. *The 55th SPE Annual Fall conference.* Dallas, TX: September. SPE 9297. 1-4

28. Davison, P and Mentzer, E (1980). Polymer Flooding In North Sea Reservoir. *The SPE 55th Annual Fall Conference*. September 21-24. Dallas, TX: SPE 9300, 353-362.

29. Bragg, J. R., Maruca, S. D., Gale, W. W., Gall, L. S, Wernau, W. C, Beek D., Goldman, I. M., Laskin, A. I. and Naslund, L. A. (1983). Control Of Xanthan-Degrading Organisms In The Loudon Pilot: Approach, Methodology, Results. *The 58th SPE Annual Fall Conference*. October 5-8. San Francisco, CA: SPE 11989. 1-5

30. Sorbie, K. S. (1991). *Polymer-Improved Oil Recovery*. The first published. USA, Florida and Canada: CRC Press. Inc. 124-125.

31. O'Leary, W. B., Bivin, J. W., Dasinger, B. L., Beck, D., Goldmain, I. M., and Wernau, W. C. (1987). Biocide Evaluation Against Sessile Xanthan Polymer–Degrading Bacteria. *Soc. Pet. Eng*. SPE 13588: 647-652.

32. Willhite, G. P., and Dominguez, J. G. (1977). *Improved Oil Recovery by Surfactant and Polymer Flooding*. New York: Academic Press Inc.

33. Szabo, M. T. (1975). Some Aspects of Polymer Retention in Porous Media Using a ^{14}C-Tagged hydrolysed Polyacrylamide, *Soc. Pet. Eng*. J. *Trans*. AIME Vol. 259: 323-337.

34. Lake, L. W. (1989). *Enhanced Oil Recovery.* Prentice Hall. Inc. New Jersey: Englewood Cliffs.

35. Camilleri, D., Engelsen, S., Lake, W. L., Lin, C. E., Ohno, T., Pope, G. and Sepehrnoorl, K. (1987). Description of an Improved Compositional Micellar/Polymer Simulator. *Soc. Pet. Eng. SPE* 13967: 1-5.

36. Lutchmansingh, P. M., Marietta, C., Ertekin, T., Abou-Kassem, J. H., (1988). Quantitative analysis of performance of polymer slug injection. *SPE Eastern Regional Meeting.* November 1-4. Charleston, WV: ESP 18534, 1-7.
37. Farouq A. S. and Thomas, S. (2000). Enhanced oil recovery- what we have learned. *J. Can. Pet, Technol*. 39: 7-11.
38. Funkhouser, G. P. and Norman, L. R. (2003). Synthetic polymer fracturing fluid for high- temperature applications. *International Symposium on Oilfield Chemistry*. February 5-7. Houston, Texas: *SPE* 80236, 1-6.
39. Shedid, A. S. (2005). Influence of fracture orientation on oil recovery by water and polymer flooding processes: An experimental approach. *Journal of Petroleum Science & Engineers* 50: 285-292.
40. Ruiquan, Z, Wei, K., Shujuan, H., Shouguo, S., Baochun, Z., and Fujun, X. (1999). Study on the Quality of Polymer Flooding Produced Crude Oil. *The 1999 SPE Asia Pacific Improved Oil Recovery Conference.* Oct. 25 – 26. Kuala Lumpur, Malaysia: SPE 57301, 1- 4.
41. Cheng, J., Wang, D., Sui, X., Zeng, H. and Bai, W. (2006). Combining Small Well Spacing With Polymer Flooding To Improve Oil Recovery of Marginal Reservoirs. *The 2006 SPE/DOE Symposium on Improved Oil Recovery*. April 22–26. Tulsa, Oklahoma, USA: SPE 96946, 1- 9.
42. Fulin, Y., Demin, W., Wenxiang, W, and Junzheng, W. (2006) A Pilot Test of High-Concentration Polymer Flooding To Further Enhance Oil Recovery. *The 2006 SPE/DOE Symposium on Improved Oil Recovery*. April 22–26. Tulsa, Oklahoma, USA: ESP 99354, 1- 8.
43. Lu, X., Wang, Y. and Zhang, Y. (2006). Strategies and Techniques for a Giant Sandstone Oilfield Development: A Road Map to Maximize Recovery. *The 2006 SPE Asia Pacific Oil & Gas Conference And Exhibition Adelaide*. September 11-13. Australia: SPE 100942, 1– 13.
44. Corlay, P., Lemouzy, P. and Eschard, R. (1992). Fully Integrated Reservoir Study and Numerical Forecast Simulations of Two-Polymer Pilots in Daqing Field. *The SPE International Meeting on Petroleum Engineers.* March 24–27. Beijing, China: SPE 22364, 331- 340.

45. Chang, H. L. (1978). Polymer Flooding Technology–Yesterday, Today, and Tomorrow. *JPT.* 1113-1128.

46. Needham, R. B. and Doe, P. H. (1987). Polymer Flooding Review. *Soc. Pet. Eng. SPE* 17140, 1503-1507.

47. Christopher, C. A., Clark, T. J. and Gibson, D. H. (1988). Performance and Operation of a Successful Polymer Flood in the Sleepy Hollow Reagan Unit. *The ESP/DOE Enhanced Oil Recovery Symposium.* April 17-20. Tulss, Oklahoma: SPE 17395, 799-810.

48. Rowalt, R. J. (1973) A Case History of Polymer Waterflooding-Brelum Field Unit. *The SPE-AIME 48th Annual Fall Meeting of The Society of Petroleum Engineers of AINE.* Sept. 30 - Oct. 3. Las Vegas: SPE 4671, 1-8.

49. Clampitt, R. L. and Reid, T. B. (1975). An Economic Polymer flood in the North Burbank Unit, Osage County, Oklahoma. The *SPE-AIME 50th Annual Fall Meeting of The Society of Petroleum Engineers of AINE.* Sept. 28 - Oct. 1. Dallas, Texas: SPE 5552, 1-8.

50. Koning E. J. L., Mentzer, E. and Heemskerk, J. (1988). Evaluation of a Pilot Polymer Flood in the Marmul Field, Oman. The *63rd Annual Technical Conference and Exhibition of The Society of Petroleum Engineers of AINE.* October 2-5. Houston, TX: SPE 18092, 1-9.

51. Tholstrom, K. V. (1976). Performance History and Operation of Two Minnelusa Reservoirs-West Semlek Field, Crook County. Wyoming. *The SPE-AIME 51st Annual Fall Technical Conference and Exhibition of The Society of Petroleum Engineers of AINE.* Oct. 3-6. New Orleans: SPE 6164, 1-12.

52. Ibrahim, Z., Abdul Manap, A. A., Abdul Hamid, P., Yee, H. V., Hong, L. P. and Wyatt, K. (2006). Laboratory Aspect of Chemical EOR Processes Evaluation for Malaysian Oilfields. *The 2006 SPE Asia Pacific Oil & Gas Conference and Exhibition.* September 11-13. Adelaide, Australia: SPE 100943, 1- 12.

53. Baxter, D., Bowman R. W., and Tinker, G. (1976). Biopolymer Pilot Facilities–Coalinga. *The SPE AIME 51st Annual Fall Technical Conference and Exhibition of The Society of Petroleum Engineers of AINE.* Oct. 3-6. New Orleans: SPE 6118, 1-8.

54. Du, Y. and Guan L. (2004). Field-Scale Polymer Flooding: Lessons Learnt and Experiences Gained During Past 40 Years. *The 2004 SPE International Petroleum Conference.* November 8-9. Pueba, Mexico: SPE 91787, 1-6.

55. Vela, V., Peaceman, D. W. and Sandvik, E. I. (1974). Evaluation of polymer flooding in a layered reservoir with crossflow, retention, and degradation. *The SPE AIME 49th Annual Fall meeting.* Oct. 6-9. Houston: SPE 5102, 1-8.

56. Shirif, E. (2000). Mobility Control by Polymer under bottom-water Conditions, Experimental Approach. *The ESP Asia Pacific Oil and Gas Conference and Exhibition.* Oct. 16-18. Brisbane, Australia: SPE 64506, 1-12.

57. Lu, H. (2004). *Improving Oil Recovery (IOR) with Polymer Flooding in A Heavy-Oil River-Channel Sandstone Reservoir*. Von der Fakultät für Geowissenschaften, Geotechnik und Bergbau der Technischen Universität Bergakademie Freiberg: Ph. D. Thesis.

58. Schurz, G. (1972). Field Preparation of Polymer Solutions Used to Improve Oil Recovery. *The Symposium on the Handling of oilfield Waters of The Society of Petroleum Engineers of AINE.* Dec. 4-5. Los Angeles, Calif: SPE 4254, 1-8.

59. Liu, B., Sun, X., Wang, K., Xu, H., Liu, Q., Liu, X. and Song, S. (2007). Flooding by High-Concentration Polymer Doubled Oil Recovery of Common Polymer on Field Test With 20% Closed to the Result of Laboratory Test in Daqing. *The 2007 International Oil Conference And Exhibition.* June 27-30. Veracruz, Mexico: 27-30. SPE 108684, 1-9.

60. Szabo, M. T. (1973). Laboratory Investigations of Factors Influencing Polymer Flood Performance. *The SPE-AIME 47th Annual Fall Meeting.* Sep. 30- Oct.3. Las Vegas: SPE 4669, 1-9.

61. Hamdan, M. K., Darman, N., Hussain, D. and Ibrahim, Z. (2005). Enhanced Oil Recovery in Malaysia: Making it a Reality. *The 2005 Asia Pacific Oil & Gas Conference and Exhibition.* April 5-7. Jakarta, Indonesia: SPE 93329, 1-6.

62. Shiyi, Y., Hua, Y., Kuiyou, S. and Puhua, Y. (1998). Effects of Important Factors on Alkali/Surfactant/Polymer Flooding. *The 1998 SPE International Conference and Exhibition.* November 2-6. Beijing, China: SPE 50916, 1-17.

63. Schlumberger. Eclipse 2000A. *Eclipse reference manual*.

64. Maschio, C. and Schiozer, D. J. (2004). Integration of Streamline Simulation and Automatic History Matching. *The SPE Annual Technical Conference and Exhibition.* September 26-29. Houston, Texas, U.S.A.: SPE 89850, 1-6.

65. Borthakur, A. S. A. and Haque, I. (2001) Water Soluble Acrylamidomethyl Propane Sulfonate (AMPS) Copolymer as an Enhanced Oil Recovery Chemical. *Energy & Fuels*, 17: 1-5.

66. Buckley, S. E. and Leverett, M. C. (1942). Mechanism of Fluid Displacement in Sands. *Trans. AIME*. 146: 107-116.

67. Demin, W., Lanshui, Z., Jiecheng, C. and Junzheng, W. (2003). Actual Field Data Show that Production Costs of Polymer Flooding can be Lower than Water Flooding. *The SPE International Improved Oil Recovery Conference in Asia Pacific.* Oct. 20-21. Kuala Lumpur, Malaysia: SPE 84849, 1-3.

68. Chang, H. L., Zhang, Z. Q., Wang, Q. M., Xu, Z. S., Guo, Z. D., Sun, H. Q., Cao, X. L. and Qiao, Q. (2006). Advances in polymer flooding and Alkaline/ Surfactant/ Polymer processes as Developed and Applied in the People's Republic of china. *Soc, Pet. Eng.* SPE 89175: 1-5.

69. Demin, W. Jiecheng, C., Junzheng, W. and Gang, W. (2002). Experiences Learned after Production more than 300 million Barrels of Oil by Polymer Flooding in Daqing Oil Field. *The SPE Annual Technical Conference and Exhibition.* September 29-October 2. San Antonio, Texas: SPE 77693, 1-10.

70. Lane, B. B. (1970). A Progress Report of Polymer Flooding - Skull Creek South Unit, Weston County, Wyoming. *The 45th Annual Fall Meeting of The Society of Petroleum Engineers of AINE.* Oct. 4-7. Houston, Tex: SPE 3052, 1-8.

71. Wankui, G., Jiecheng, C., Yuming, Y., Chuanhong, L., Wenxue, L., Qun, L., Junde, L. and Junzheng, W. (2000). Commercial Pilot Test of Polymer Flooding in Daqing Oil field. *The 2000 SPE/DOE Improved Oil Recovery Symposium.* April 3-5. Tulsa, Oklahoma: SPE 59275, 1-10.