A Review on Enhanced Oil Recovery Methods and Techniques in Different Reservoirs Rock Types, Conditions and Its simulation

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ABSTRACT In view of the current vast worldwide oil extraction and production, the reservoirs storage capacities lessening scenario, the imminent fast oil production depletion in foreseeable near future and due to the fact that very rich volume of heavier residual oil still remaining down inside the trapped reservoirs that account for 40-60% in total; endeavors to salvage and increase oil production of abandoned matured oil fields become critical. The high volume of heavier oil deposit is hard or impossible to be extracted by normal methods, they are still scattering in all the abandoned or semi-abandoned matured oil fields around the world. Considering of the uncertainties and escalations of worldwide oil prices in the last thirty years, numerous methods and techniques have been derived to revive matured oil fields production. These remaining residual heavier oil deposits that normal extraction by making use of reservoir pressure, pumping and conventional water injection or simply by water flooding could not handle. Steam injection, thermal combustion, chemical (polymers, surfactants), gas, microbial and other methods have been used to continue to improve the extraction of heavier residual oil. This stage of enhanced oil recovery and production are commonly called tertiary oil production or enhanced oil recovery. Current research literature review paper here is to bring forward the detailed nature or types of reservoir rocks (tight shale, sandstone, carbonate and conglomerate) conditions and methods including simulation to understand the essential part of enhanced oil recovery.

KEYWORDS: Enhanced Oil Recovery; Reservoir rocks; thermodynamic model; Black oil Model, MRST simulation.
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INTRODUCTION

Research and development in enhanced oil recovery (EOR) techniques and methods in different reservoir rock types, condition and its simulations are the hot topics, subjects of discussion, investment of the governments and agencies of large corporate companies worldwide. As the subject of enhanced oil recovery have been seriously considered by major oil producing countries due to the fact that many of current oil producing oil fields or reservoirs are becoming matured, techniques and methods to further development of these matured oil fields that still containing of 40-60% of heavier crude oil are deemed necessary or relevant to enhanced oil recovery to cope with worldwide economic requirement. To ensure and maintain the provision of dependable power supplies economically, all research institutes are competing with each other in finding out the best economic methods and new techniques for tertiary oil recovery throughout the world.

In this review study, attention have concentrated on residual oil extraction methods, techniques, including computer MATLAB-MRST simulation program that has been or currently being engaged in worldwide enhanced oil recovery in tight shale, sandstone, carbonate and conglomerate rock type reservoirs. Certain gases such as carbon dioxide, nitrogen, hydrocarbon, surfactant and polymer including others that have yet to appear have been considered and used to study and struggle to find out which would be the best for enhanced oil recoveries. Rock type studies to know the sizes and properties of their density, permeability, viscosity, mobility of water, surfactant, polymers and other chemicals related issues have been carried out for decades. As a result of these activities for so many years, researchers are able to devise all types of Model equations deriving from equation of state, physical modeling, reservoir modeling, three-phase Black oil/polymer modeling and etc. to form the major current research tools to further enhance development in major oil fields and institutes of higher learning of oil producing countries throughout the world.

OIL RECOVERY METHODS

Recent analysis based on reservoir lithology and exploration screening and consideration of EOR Methods for 1507 International projects, a database has been created for EOR in sandstone, carbonate, and other rock type reservoirs (Alvarado & Manrique, 2010). It has been indicated that the current extraction of oil rock types are sandstone: 78%, carbonate: 18% and others: 4%, respectively. This is summarized in Figure 1.

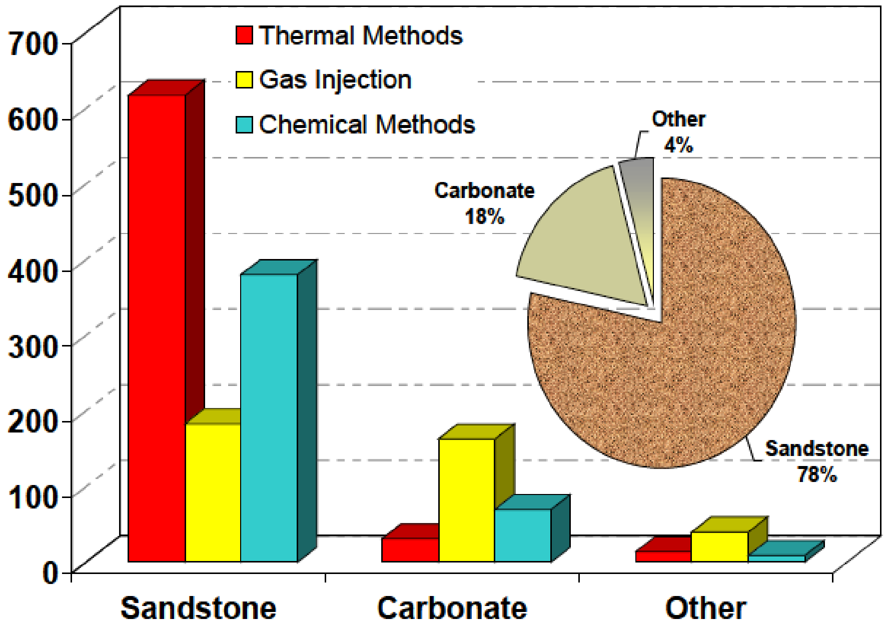

Figure 1. EOR Methods by Lithology Based On a Total of 1,507 Projects (Adapted from Alvarado & Manrique, 2010)

Thermal Method

In combined polymer/hot water flooding studies (Littmann, 1988), it was found and suggested that temperature of hot polymer flooding should be in between70 ℃ and 110 ℃ and noted that temperature higher than this would cause synthetic polymer unstable due to its internal degradation. Study on heavy oil recovery by polymer flooding with hot water injection, thermal and chemical flooding have been good alternatives to recover heavy oils (Bordeaux*et al.*, 2017). It has been commonly known that hot water injection decreased oil viscosity but contained unfavorable mobility ratio resulted in an inefficient sweep. As understood Polymer flooding increased sweep efficiency due to its higher viscosity than water but might produce low polymer injection result.

In their recent research (Bordeaux et al., 2017), the researchers have combined both of the above techniques to improve oil recovery and noted that hot water improved polymer injection and the higher viscosity of polymer increased mobility ratio; but it was also well known that polymer thermal degradation due to the complex combination of the techniques decreased oil recovery ratio. As such, the effectiveness of the polymer would also be affected. Analysis of impact of different injection temperature of combined polymer and hot water flooding improved both production and economic indicators and using numerical simulation have also been carried out.

Applying reliable polymer viscosity and degradation modeling linked to temperature with the best injection temperature were found in between 25℃ and 200℃ (Littmann,1988). Heterogeneous heavy oil field simulation model has been used and tested with various injections that have been carried out. With the input of Adjusted Arrhenius equation, the polymer thermal degradation reaction with the parameters of polymer viscosity depend on temperature from the literature of water-based flooding strategy was devised and used. It was also confirmed that 100 ℃ was the optimum temperature for both oil recovery and economic consideration.

Gas Injection Method

EOR CO_2 injection for heavy oil has been conducted. The carbon dioxide (CO_2) injection mechanism contributed much in enhanced oil recovery (EOR) and achieved oil viscosity reduction. CO_2 input have been considered impressive(Seyyedsar *et al.*, 2016). Mixing or dissolution showed that extraction of hydrocarbon with the adding of CO_2 was deemed promising. Based on the test results, the composition analysis of the core samples confirmed that tertiary injection of CO_2 changed the physical properties of heavy oil in the cores and produced better oil that proved to be able to lower density as well as viscosity of oil than the original oil in place (OOIP).

There are other types of Gas injection including Nitrogen (N_2) as chaser mixed with CO_2 in maximum of 20:80 proportion or CO_2 mixed with Hydrocarbon (HC) have been applied in Modern EOR Methods. CO_2 injection into light oil reservoir condition under low pressure was by huff 'n' puff process and was studied experimentally and have been found that using N_2 as chaser have potential in improving CO_2 injection efficiency. The solubility of CO_2 in crude oil and oil swelling factor could be experimentally found based on interfacial tension (IFT) reduction and swelling test results. Mixing of original light crude oil (Abedini & Torabi, 2014) with CO_2 by setting of CO_2 pressure to Pmmp=9.18MPa and a temperature at 30℃ has been carried out, and when the injection and mixing achieved optimum condition, hydrocarbon extraction could be started at the extraction pressure of $P_{extract}$ = 6.8MPa. It was noted by other researchers that operating pressure near Minimum Miscible Pressure (MMP) and beyond Minimum Miscible Pressure (MMP) no apparent EOR effectiveness found (Mollaei *et al*., 2011).

Chemical Method

EOR by chemical formulation and injection techniques involved polymer/surfactant/polymer and alkaline/surfactant/polymer mixing have formed the most efficient sweep and displacement to enhance oil recovery lately and these methods have been carried out on real reservoirs condition (Goudarzi *et al*., 2016). Further discovery found that for mature oil reservoirs, the use of polymer as secondary injection; as well as use of surfactant injection for tertiary enhanced oil recovery methods have been considered essentially applicable. Researchers have also compared of their computational efficiency, solution algorithms and on process modeling comparison experiments. Application of variance based sensitivity analysis on surfactant/polymer flood by modified chemical flood predictive model were studied (Lake, 1989; Mollaei *et al*., 2011) and injection of chemicals to water-flood to alter Fluid wettability to the rock surfaces with the aim to decrease interfacial tension (IFT) with surfactant, alkaline and polymers have been carried out by the mentioned researchers. Numerical modeling of compositional flow to study stability in Chemical EOR have found that oil recovery factor depend very much on surfactant properties (Seyyedsar *et al.*,2016). Studies and reports of chemical EOR on matured or depleted conventional light oil reservoir also have been carried out by other researchers (Delshad *et al*., 2013; Abedini & Torabi, 2014).

Most Commonly Used EOR Polymers

Synthetic and biopolymers that have been used in EOR are of the synthetic categories, these including partially HPAM (hydrolyzed polyacrylamide), modified natural polymers, biological polysaccharide and Xanthan gum. Hydroxyl ethyl cellulose (HEC), sodium carboxymethyl cellulose and carboxyethyl cellulose have also been categorized as synthetic polymers. Polyacrylamide (PAM) has been used as thickening agent for aqueous solutions. Partially hydrolyzed polyacrylamide (HPAM) has been mostly used in EOR and contain co-polymer of PAM and PAA (polyacrylamide acid). HPAM has been preferred in EOR because of its ability to enhance polymer thermal stability in reservoir.

ROCK SIZES

Rock Sizes on the PVT Properties

Rock pore sizes affect permeability, fluid properties and it has been found that some rocks with very low permeability have represented challenging in their consideration in oil and gas retrieval and extraction (Kamari *et al*., 2017).The same authors have studied on Rock pore sizes on PVT properties for both conventional and unconventional reservoirs with models. They have developed models to calculate bubble point pressure and have carried out thermodynamic modeling to observe effects of pore sizes on PVT properties. The same researchers have also studied impact of capillary pressures on phase envelope and also on large capillary pressure of Nano-pores on pressure-temperature phase envelope on shale oil and gas-condensate.

ENHANCED OIL RECOVERY IN DIFFERENT TYPES OF RESERVOIRS

Shale and Tight Reservoir EOR

Shale rocks composed of very low permeability in quality and directly related to rock pore sizes in connection to PVT oil and gas condensates of shale and tight reservoirs. Researchers have able to correlate the pore sizes dependent on capillary pressure by using phase equilibrium equations and have successfully computed with different promising results(Kamari *et al*., 2017).

Rock Sizes, PVT Properties and Set Up of Thermodynamic Model:

Thermodynamic model have been developed and were able to simulate results by good model setup in oil and gas condensate study (Kamari *et al*., 2017). Starting from study of very low permeability and different fluid properties of rocks have been carried out. Research work with the application of the established thermodynamic modeling and setup based on the generalized form of the equation of state and Peng-Robinson equation of state with taking consideration of all properties and parameters including bubble and dew point pressures of gases, viscosity, density, interfacial tension, capillary pressure, rock pore sizes have been carried out. Validation of the model have been done based on published data of a numerical model with capillary pressure consideration (Nojabaei *et al*., 2016). Two-phase envelope of the binary mixtures with different model fractions (C1:C6=7:3, 5:5 and 3:7) examined at the pore radius of 20nm and found that the results from the model developed called modified model was accurate and applicable for computation of the effect of Nano-pore size on capillary (Kamari *et al*., 2017).

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<u>*Sandstone Reservoir EOR*</u>

Experimental Investigation of Tertiary CO_2 Injection:

Two experiments on heavy oil recovery under reservoir (High purity sandstone rock) condition by injection of CO_2 into two water-flood experiment samples have been experimented (Seyyedsar *et al.,* 2016). Recovery efficiency of natural depletion from heavy oil reservoir have been found low due to the fact of fairly low dissolved gas contents and high oil viscosity. Apart from thermal method, non-thermal recovery has been used to increase oil recovery from heavy oil reservoirs.

Application with Water Flood, Brine, Polymers, Surfactant, Gas and Chemicals:

Water-flood to heavy oil reservoirs has found with poor recovery factors and it has been noted that most of the water-flooded with brine has been from light oil reservoirs. Efficiencies could be further enhanced with suitably selected chemicals or reservoirs that injected with adequate brine and polymer; and this would improve the sweep or flow of residual oils in the targeted reservoir rock formations (Skauge & Shiran, 2013).

Others also aware that injection to high viscosity reservoir required higher injection pressure, and found that heavy oil reservoirs were relatively shallow and have maximum formation pressure lower than the design pressure for polymer injection (Seyyedsar *et al.,* 2016), and thus become a great challenge for higher pressure injection to extract oil of this type. It was also found that surfactant could enhance microscopic recovery and reduce capillary forces and favor oil extraction. Gas injection formed another important way of recovering oil from depleted oil reservoirs. However, gas injection also has its limitation (poor sweep efficiency) due to reservoir heterogeneity, low density and low viscosity of gas (Skauge & Shiran, 2013).

Miscibility between the oil and injected gas could not be achieved at the actual condition of heavy oil reservoirs because of the nature of high viscosity and low API gravity of the oil. It has also been noted of the advantages for heavy oil recovery caused by mixed and mass exchanged between CO_2 and oil. As such, CO_2 would be a dense fluid under the condition of heavy oil reservoirs if the pressure of the reservoirs were adequate. In tertiary CO_2 injection investigation experiments for EOR and recent study of extra heavy crude oil samples (Seyyedsar *et al.*,2016) with density of 0.9908g/cm^3 at 25 ℃ have been used in the core-flood and interesting experiment results were obtained and extracted for this review purpose in the following(Table 1-3).

Table 1. Heavy Oil Test Samples PVT(Adapted from Seyyedsar *et al.*, 2016)

Experiment	Temperature (℃)	Pressure (psi)	Dissolved in Oil	GOR (scm^3/ton^3)	Viscosity(c P)
1	28	1500	CH_4	23.75	12100
1	28	1500	CO_2	66.25	717
2	50	1500	CH_4	22.10	1665
2	50	1500	CO_2	56.90	219

Table 2. Brine Test Samples PVT (Adapted from Seyyedsar *et al.*, 2016)

Experiment	Dissolved gas in Brine	Temperature (℃)	Pressure (psi)	GOR (scm³/ton³)	Viscosity (c P)
1	CH4	28	1500	3.43	0.890
1	CO2	28	1500	32.73	0.899
2	CH4	50	1500	3.00	0.562
2	CO2	50	1500	26.70	0.597

Table 3. CO_2 Under Conditions of Experiments-Physical Properties (Adapted from Seyyedsar *et al.*, 2016)

Experiment	Temperature (℃)	Pressure (psi)	(g/cm3)	Viscosity	State
1	28	1500	0.798	0.070	Liquid
2	50	1500	0.426	0.031	Supercritical

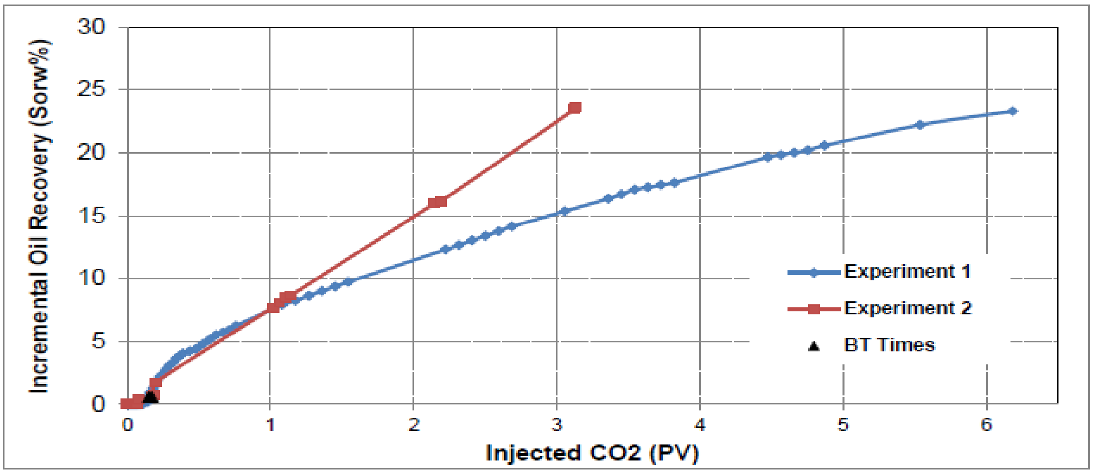


Figure 2. Experiment Result: Oil Recovery with CO_2 in EOR (adapted from Seyyedsar *et al.*, 2016)

It was noted by Seyyedsar *et al.* (2016) that the experiment results of the above incremental oil recovery, both showed (Figure 2 and Table 3) that the tested heavy oil's viscosity were greatly reduced and oil recovery rate increased greatly.

Experiment Procedure Description and Discussion of Experiment Result:

Two (2) tertiary continuous CO_2 injection experiments have been carried out to evaluate the impacts of oil viscosity and CO_2 density on the performance of heavy oil recovery under reservoirs conditions described thoroughly through detailed experiment (Seyyedsar *et al.*, 2016). Extra heavy oil with density 0.9908 g/cm³ at 25℃ was used in the Core flood test. In Table 1 the Heavy Oil Test samples under two different temperature of 28℃ and 50℃ at same pressure of 1500psi with additive CH_4 and CO_2 injection during the core flood test; it was found that at higher temperature the viscosity of heavy oil tested was greatly reduced and CO_2 performed very much better than CH_4.

In Table 2, the Heavy Oil Test samples with Brine injection have been subjected to same condition of both temperature and pressure. The result showed that Viscosity has been greatly reduced at higher temperature and when temperature prevails, it influenced the core flood very much and CO_2 in this case also performed better. In Table 3, the Heavy Oil Test Samples with CO_2 injection with different temperature range, maintained at same pressure and the result showed that with higher temperature the core flood samples viscosity have been greatly reduced. It was found that in all test results carried out, CO_2 performed better in reduction of viscosity in core flooding at higher temperature.

Carbonate Reservoir EOR

Oil Recovery Using N_2, HC Gases and CO_2 Injection:

Researchers (Belhaj *et al.*, 2013)have proposed and carried out tests in their studies by CO_2 miscible injection and improvement by N_2 and HC injection. It was found that with the increase in injection of N_2 into CO_2 it increased the minimum miscibility pressure (MMP) and in later stage, experiment has shown that an amount of maximum 20% of N_2 could be mixed with CO_2 and injected into the intended test sample(s) or the target oil produced the best results. This means that the results of the effects of oil swelling, oil stripping and viscosity reduction have been suppressed with increase of N_2injection percentage into CO_2.

Miscible Oil Recovery in Carbonate Reservoir:

Simulation with the use of computer modeling group's (CMG) WINDROP module software have been carried out (Belhaj *et al.*, 2013) to identify CO_2 solvent mixture with reduced minimum miscible pressure (MMP) effectiveness to targeted oil for carbonate reservoir efficiency test. With this method, prediction result of miscibility could be obtained, and it has been found that it enhanced oil recovery factor.

Experiment Finding:

The same researchers (Belhaj *et al.*, 2013) have also found that the test study has shown strong agreement between the predicted minimum miscible pressure (MMP) using Peng-Robinson-Equation of state (PR-EOS) and the experiment values measured by vanishing interfacial tension (IFT) techniques. Different tuning approaches show that tuning of equation of state (EOS) may not always be suitable for calculations of minimum miscible pressure (MMP). Other researchers (Chen *et al.*, 2017) also noted that Equation of state (EOS) gave good prediction of the PVT data and would not necessarily guarantee an accurate minimum miscible pressure (MMP) prediction.

It was noted that (Belhaj *et al.*, 2013), the effects of oil swelling, oil stripping and viscosity reduction were further suppressed by increasing N_2 content and it would lead to higher minimum miscible pressure (MMP). As the process shot up above the threshold value of about 20% N_2, the miscibility of the CO_2/N_2 injected gas could be estimated by evaluation of miscibility of N_2 with the target oil as mentioned. It was concluded that CO_2 composition lower than 80% or N_2 above 20% miscibility was not significant (Belhaj *et al.*, 2013). The shortcoming of this study was that no experiment test result could be used to convince the simulator result.

Conglomerate Reservoir EOR

Optimization of Polymer Flooding

Conglomerate formation of oil field in Karamay have been studied (Liu *et al.*, 2017) and oil composition of the two formations have been shown in Table 4.

Table 4. Oil Composition of two Conglomerate Formations Upper and Lower Karamay Formations (Adapted from Liu *et al*., 2017)

Oil composition	Saturated Hydrocarbon, %	Aromatic hydrocarbon, %	Colloid, %	Asphaltene, %
Upper formation	65.92	9.77	20.95	3.36
Lower formation	68.12	13.35	16.45	2.08

Conglomerate Reservoir Polymer Flooding Design and Challenges Faced:

New EOR technique for conglomerate reservoir, polymer flooding has been adopted to ensure sweep efficiency. The relationship between polymer molecules, pore throat radius and mobility control have been matched and integrated to explore an acceptable viscosity range for a polymer flooding in conglomerate reservoirs and Karamay conglomerate reservoir has been used as a field case that possessed the permeability of 50-200 mD (mili-darcy) and finally the researchers (Liu *et al*., 2017) have come up successfully with a proposed range of polymer viscosity for Karamay conglomerate reservoir.

Thin section analysis in Figure 3 and mercury injection capillary pressure (MICP) curve in Figure 5 on a reservoir rocks were used to study the pore structure.

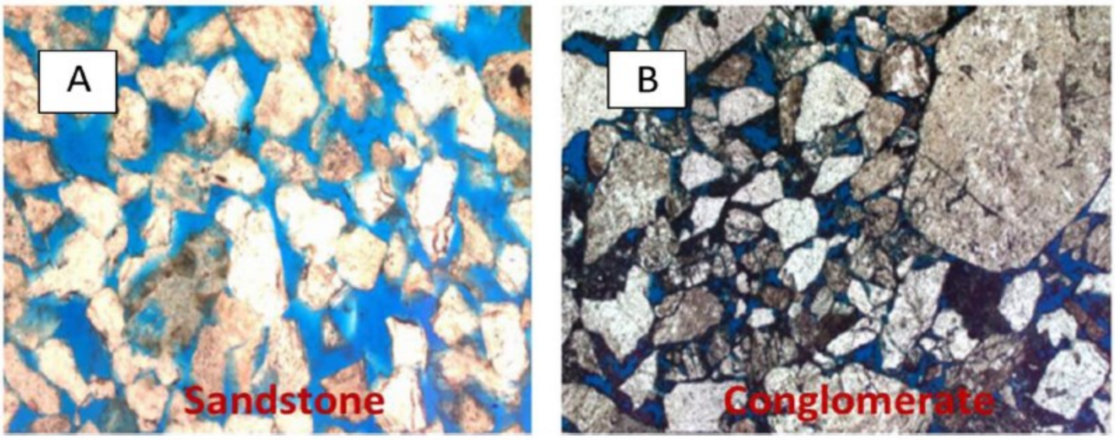


Figure 3. Thin Section Photo of Sandstone (A) and Conglomerate (B) (Adapted from Liu *et al*., 2017)

Karamay Formation Reservoir Properties

The Karamay formation reservoir properties are given as follow.

1) Upper Karamay formation of river delta sedimentation and average porosity: 20.1% and permeability : 121 mD (mili-darcy)
2) Lower Karamay formation of alluvial fan sedimentation and average porosity: 16.7 % and permeability : 49 mD
3) Distribution of sandstone grain size was more uniform than conglomerate.
4) Absolute permeability is shown in Figure 4.
5) Cores and polymer properties of some of Karamay formations also have been shown in Table 5.

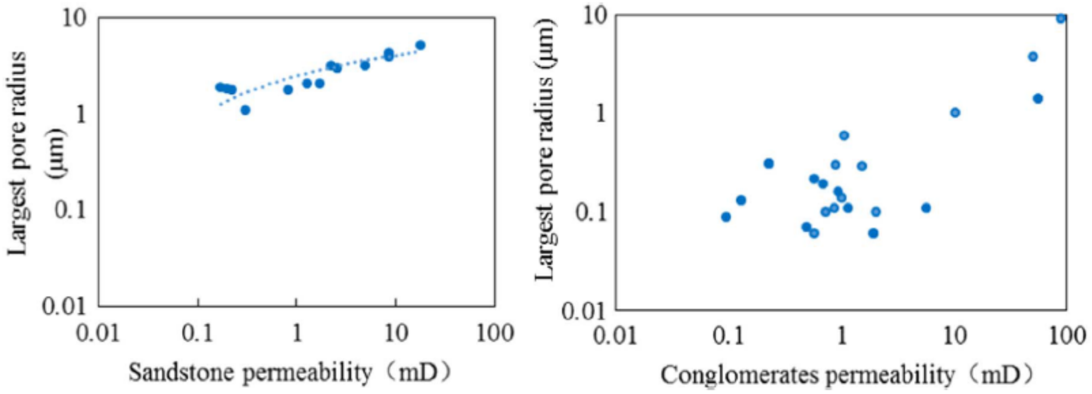


Figure 4. Pore Radius and Permeability of Sandstone and Conglomerate (Adapted from Liu *et al.*, 2017)

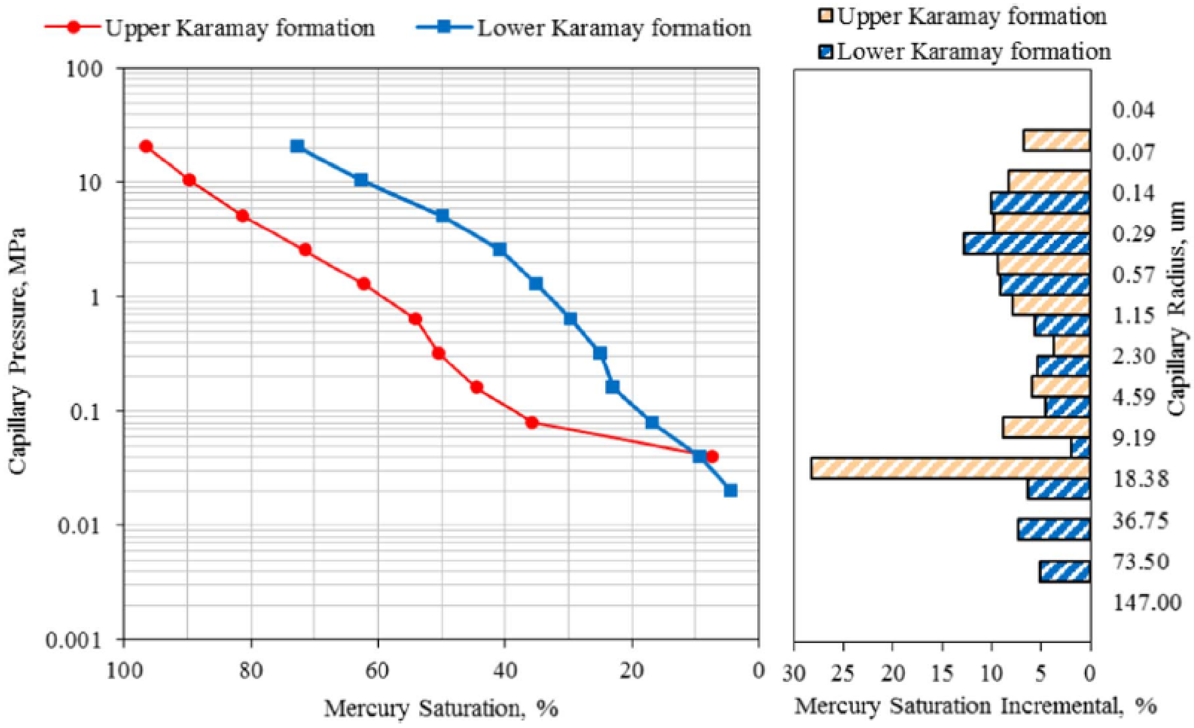


Figure 5. Pore Throat Size in Conglomerate Rocks of two Formations with Same Permeability (Adapted from Liu *et al.*, 2017)

Polymer Viscosity Design on Karamay Formation and Result Discussion

The polymer viscosity versus hydrodynamic characteristics based on favorable mobility ratio design principle that followed with acceptable viscosity range have been studied and shown in Figure 6 to ensure mobility control effectiveness.

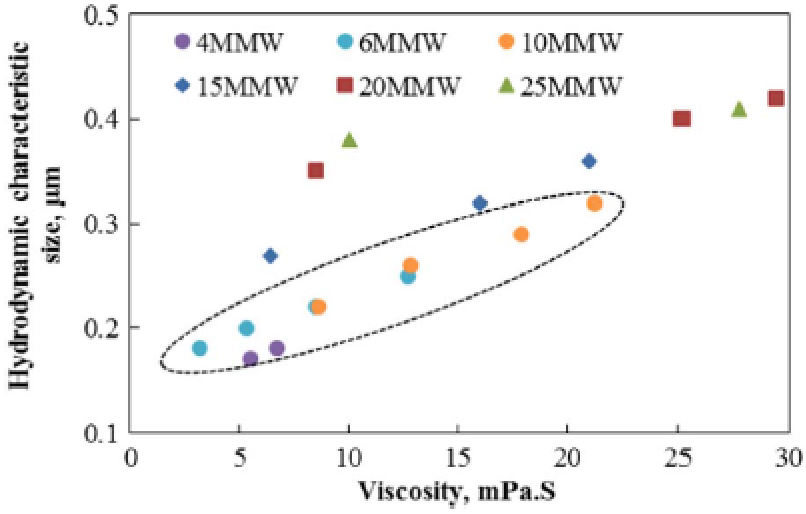


Figure 6. Viscosity and Hydrodynamic Characteristic Size (Adapted from Liu *et al*., 2017)

The researchers have carried out Six (6) experiments and each equipment/instrument has performed with three (3) velocities. Based on the outcome of their studies it was found that the polymer has good control in mobility.

Table 5. Summary of Core and Polymer Properties (Adapted from Liu *et al*, 2017)

Property	Sandy Conglomerate (Upper Karamay)	Inequigranular Conglomerate (Lower Karamay)	Sandstone (Outcrop)
Porosity	0.19	0.17	0.22
Length, cm	7.21	6.89	9.59
Diameter, cm	3.65	3.65	2.51
Area, cm^2	10.46	10.46	4.95
Pore Volume, cm^3	14.33	12.25	10.44
Brine Permeability, mD	129	49	145
Polymer Molecular Weight, Million Dalton	20	10	20
Polymer Concentration, ppm	1000	1200	1000
Polymer Solution Viscosity at $7.34S^{-1}$, cP	25.1	8.6	25.1
Residual Resistance Factor	2.0	2.1	1.6

Researchers found that oil production was increased by $13\text{x } 10^4$ tons and water cut was down by 15% during polymer flooding as shown in Figure 7 (Liu *et al*., 2017).

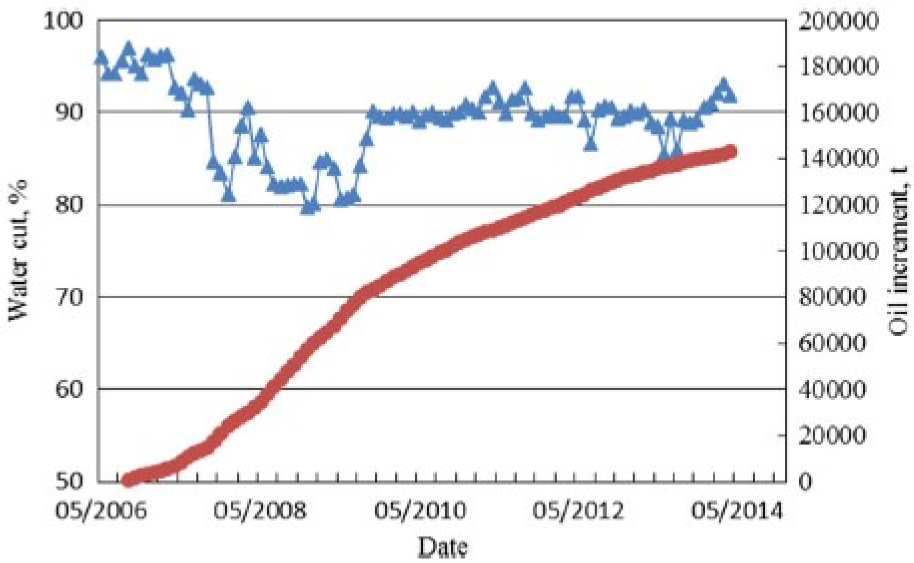


Figure 7. Development Curve of Polymer Flooding of Karamay Field in term of Oil Capacity and Water Cut Information (Adapted from Liu *et al*., 2017)

Discussion of Polymer Flooding in Sandstone and Conglomerate Rocks:

Table 4 shows oil composition of two formations (Upper and Lower Karamay Formations) of Conglomerate Rocks of Karamay Oil Field and in Table 5 shows the summary of Cores and Polymer Properties of conglomerates (at Sandy Conglomerate and Conglomerate) and sandstone (at Outcrop) used in Polymer Flooding there. Figure 6 shows Viscosity versus Hydrodynamic characteristic sizes of rock properties and in Figure 7 describes the result of successful Polymer Flooding in Karamay Oil Field in term of Water Cut and Oil Recovery Rates during the Production Polymer Flooding from May 2006 to May 2014 Period.

<u>*Light Oil EOR*</u>

Study of Cyclic CO_2Injection:

Cyclic CO_2 injection in light oil EOR has been suggested (Ma *et al*., 2016) on the Huff-n-Puff (HnP) CO_2 injection in cycles in the following operations procedure: 1) injection 2) shut-in and 3) production. Pre-designed gas slugs were placed and CO_2 injected into the candidate reservoir. During the shut-in time the reservoir well has been closed for a period of time to allow mixing and reaction with reservoir fluids and then production allowed for the rest of the test well.

Description on Cyclic CO_2 Injection

The Injection-Soaking-Production cycles of CO_2 as mentioned continuous to take place until attained the most unfavorable EOR output in time lapse. The authors (Ma *et al*., 2016) have cited with several researcher's findings, a numerical and laboratory study that: 1) trapped gas saturated as a result of rapid pressure decline during production and 2) the reduction in water/oil interfacial tension (IFT) or the alteration of wettability have been achieved during their cyclic CO_2 injection period. The researchers also quoted that shorter soaking time achieved better result in oil recovery for CO_2 injection.

Researcher's Result Findings and Discussion

The authors (Ma *et al*., 2016) unconvincingly quoted some other researchers' contradictory findings that CO_2 Huff-n-Puff (HnP) injection was good at low pressures as a result of increasing

CO_2 core volume at lower pressures; whilst they have also mentioned that some laboratory's findings that CO_2 injection with high reservoir pressure condition were most favorable. The authors also found and quoted that by injection of pure CO_2 only, the co-injection of CO_2 with N_2 gases as studied have potential to further improving the CO_2 efficiency in EOR.

The same authors (Ma *et al*., 2016) have demonstrated in their studies that viability of CO_2 injection of enhanced oil recovery for low pressure reservoir carried out have shown good results at different experiment conditions and have achieved explanatory favorable results and according to their findings that as high as 28.90% (Test 3) to 32.13% (Test 4) oil recovery from original oil in place (OOIP) have been achieved after the first three to four cycles of experiment, as shown in Table 7 and these results have been taken as the dominant contributors for this purpose in cyclic CO_2 injection.

Table 6. Reservoir Condition and Property (Adapted from Ma *et al*., 2016)

Permeability (mD)	Porosity (%)	Temperature (°C)	Pressure (MPa)
117.0	19.1	33.9	6.58

Table 7. Summary of Cyclic CO_2 Core Flood Result (Adapted from Ma *et al*., 2016)

Run no.	Maxi Pressure (MPa)	Cycle RF (%)	Test no.	Ultimate RF (%)
1	11.40	14.3	Test 1	24.18
2	5.35	5.7		
3	4.85	3.48		
4	4.05	0.7		
5	14.00	12.9	Test 2	31.52
6	9.25	7.49		
7	8.64	4.63		
8	8.40	2.42		
9	7.69	1.08		
10	13.50	13.8	Test 3	28.90
11	8.89	7.06		
12	8.21	4.69		
13	7.89	2.46		
14	7.39	0.89		
15	13.30	16.2	Test 4	32.13
16	9.04	8.48		
17	8.42	4.07		
18	8.61	2.21		
19	7.51	1.17		

Table 7. Summary of Cyclic CO_2 Core Flood Result (*cont*)

Run no.	Maxi Pressure (MPa)	Cycle RF (%)	Test no.	Ultimate RF (%)
20	11.40	9.47	Test 5	24.80
21	11.40	7.06		
22	11.40	4.72		
23	11.40	2.42		
24	11.40	1.13		
25	11.40	10.2	Test 6	26.06
26	11.40	7.43		
27	11.40	5.11		
28	11.40	1.98		
29	11.40	1.34		
30	8.15	7.7	Test 7	17.33
31	6.88	4.62		
32	12.30	5.01		
33	11.71	8.32	Test 8	18.80
34	10.90	6.33		
35	12.60	4.15		

Discussion of CO_2 Injection in Light Oil EOR Findings:

Table 6 shows the characteristics of light-oil field reservoir condition for the study of permeability (117.0 mD), porosity (19.1%), temperature (33.9 ℃), and pressure (6.58 MPa), respectively. Table 7 shows the summary of cyclic CO_2 core flood results that involved the number of runs, with maximum pressure (MPa) achieved and ultimate oil recovery factors attained. It was shown that the highest oil recovery rate attained at Test 4 with oil recovery of 32.13% at run 15 and it was also shown that injection of cyclic CO_2 into low pressure reservoir to extract residual oil becoming fruitful in the industry; and the result of high recovery rate in oil production with cyclic CO_2 injection have been also shown in Table 7. It has been considered and concluded in the experiment study that cyclic CO_2 flooding for light-oil reservoirs are having promising prospects in residual oil extraction.

RESERVOIR SIMULATION

Polymer Flooding Simulation

Fully implicit simulator for polymer injection using MATLAB Reservoir Simulation Toolbox (MATLAB-MRST) have been studied and found that it has been very versatile and useful. Computer aided software application could provide accurate simulation under real reservoir conditions (Bao *et al*., 2017a). The versatility of the MATLAB-MRST program developed for real reservoir condition have been demonstrated and described in great detail by the researchers.

The Black Oil Model

Researchers have developed full MRST program incorporated with Model equation called the Black Oil Model/equation (Li *et al*., 2003; Bao *et al*., 2017a) as computer tools in solving EOR calculation problem. The MRST black oil model has been applied successfully on reservoir simulation of unstructured grids. It was also found that the implicit method was very subtle and complicated in terms of the physical complexities and the irregularities of the grids and as a result it involved the use of a very complicated linear equation system structure for processing immense data with large database and incurred heavier in simulation cost.

The Black oil model have been further improved (Li *et al.*, 2003b). As such, Black oil sequential method developed are able to reduce the size of large linear equation systems and can solve instability of the low implicit degree of the black oil model method during the simulation. The authors have demonstrated that by use of this sequential method in under-saturated reservoirs simulation reduced almost 70% of computer time than the implicit black oil method. However, for a saturated reservoir the convergence and accuracy depended on whether free gas was injected and it was reported that even without this element the method still ensure convincing results, but in terms of gas injection case the pressure of gas and oil ratios (GOR) result might generated deviation from the actual performance of the implicit method. It was recommended that stricter iteration control must be incorporated to ensure achieving the identical degree of precision of the implicit methods.

The Polymer Model

This model equation consists of factors of polymer concentration in units of mass per volume of water, maximum concentration, adsorption concentration, the density of the reservoir rock and the inaccessible or dead pore volume. The reduced mobility of the mixture of pure water and diluted polymer has been modeled by effective mixture of viscosities that depend on the polymer concentration, result in a modified Darcy equation form and the non-decreasing function models. The reduced permeability experienced by the water and polymer mixture as a result of adsorption of polymer onto the rock's surface happened. In the studies, the model equation parameters have also considered the inclusion of: 1) Inaccessible pore space, 2) adsorption, 3) permeability reduction and 4) effective viscosities (Bao *et al*., 2017a).

Rheology of the Polymer Solution

Viscosity or thickness of fluid was defined as ratio between shear stress and the shear rate. Measurement of the resistance of a fluid was to change its form have also been discussed. Polymer solutions has shear-thinning viscosities as shear rates increase, the authors (Bao *et al.*, 2017a) have presented with a commercial simulator in their model analysis and assumed that shear rate of water was proportional to the water velocity and could be applied to a single rock type within reservoir.

The MRST Program Software Structure for Simulation Purpose Comprised of the Followings:

1. Building up grids and discrete differentiation operators;
2. Computation of flow equations for Black oil
3. Derivation of Automatic Differentiation in MRST;
4. Black oil Simulator; and
5. Object orientated implementation in MRST (Bao *et al*., 2017b).

Three Phases Black Oil Simulator in MRST

The same authors (Bao *et al*., 2017b) have discussed ways to discretize and solve the basic black oil equations and how to implement and solvers using functionality for rapid prototyping from open source MRST software to obtain simulator framework. According to the same authors, many of these modules offered standalone functionality and built on top of MRST core and standard MATLAB subroutines and the authors have focused on the use of the MRST- AD, AD-OO family modules rapid prototyping of fully implicit simulators in their studies.

The Polymer Flooding Simulator Application of Using MATLAB Software

The authors have developed and presented free and open source MATLAB-MRST software for a number of interested researchers' use within the computational Geosciences as shown in Figure 8 (Modules used to implement a fully implicit surfactant and polymer water-based EOR simulator). This system of software package has been updated and furthermore completed with the inclusion of features of discrete differentiation operators, automatic differentiation, and object-oriented programming framework.

With the recent update and improvement as mentioned, the MATLAB-MRST software program according to the authors' view are considered to be as versatile as the commercial or industrial-grade simulator tool for polymer, alkali-surfactant-polymers simulation in 2D and 3D. Capabilities have been shown in Figure 9 (Flow chart to define the three phases, black oil, reservoir, surfactant and polymer models).

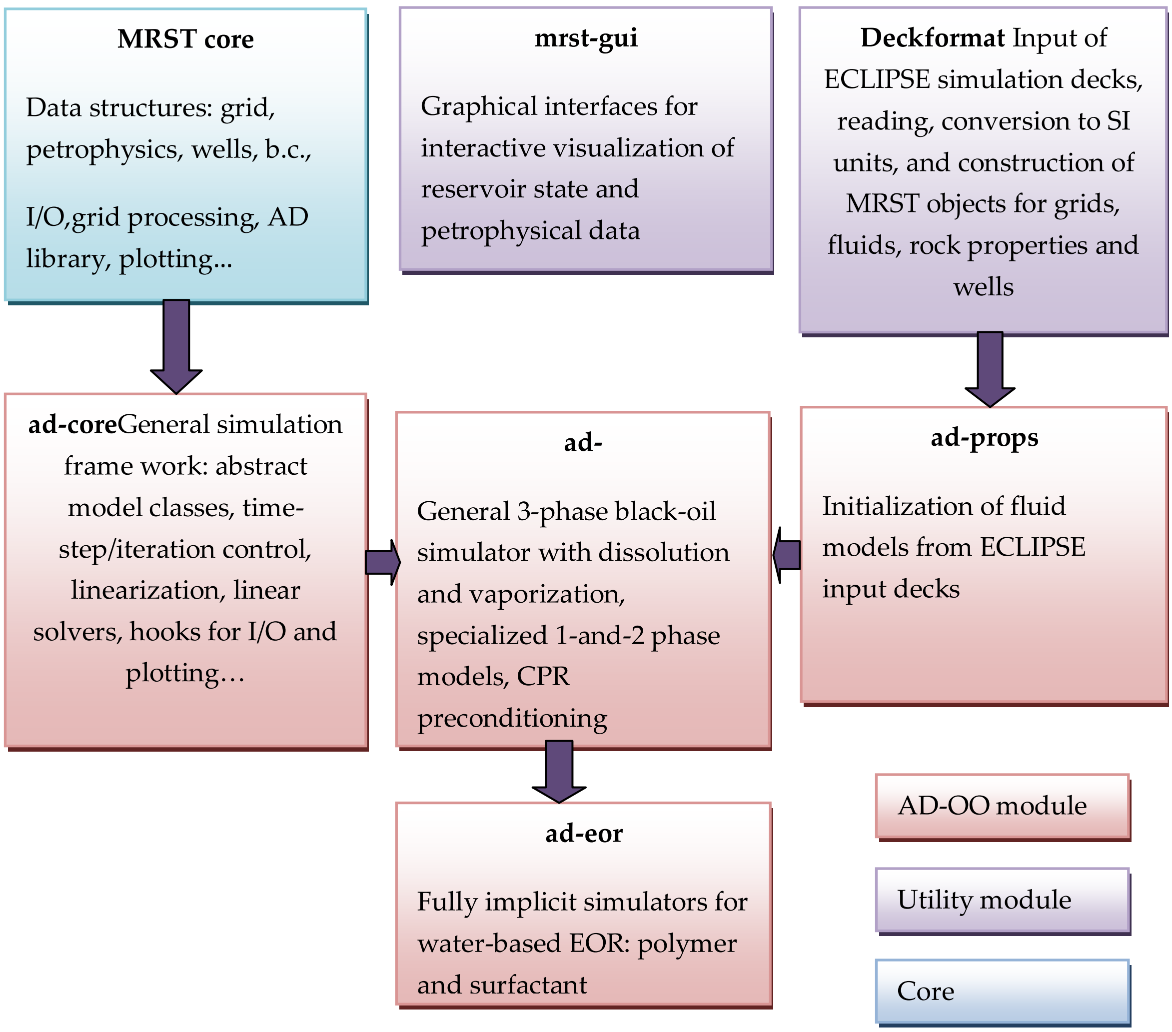


Figure 8. Modules used to implement a fully implicit polymer simulation (Adapted from Bao *et al.*,2017a)

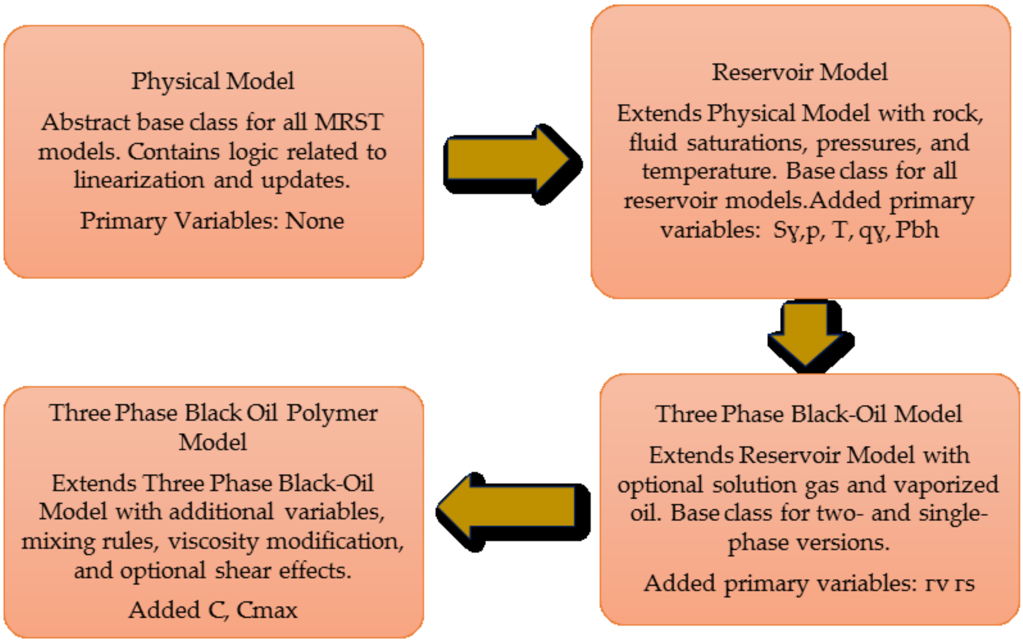
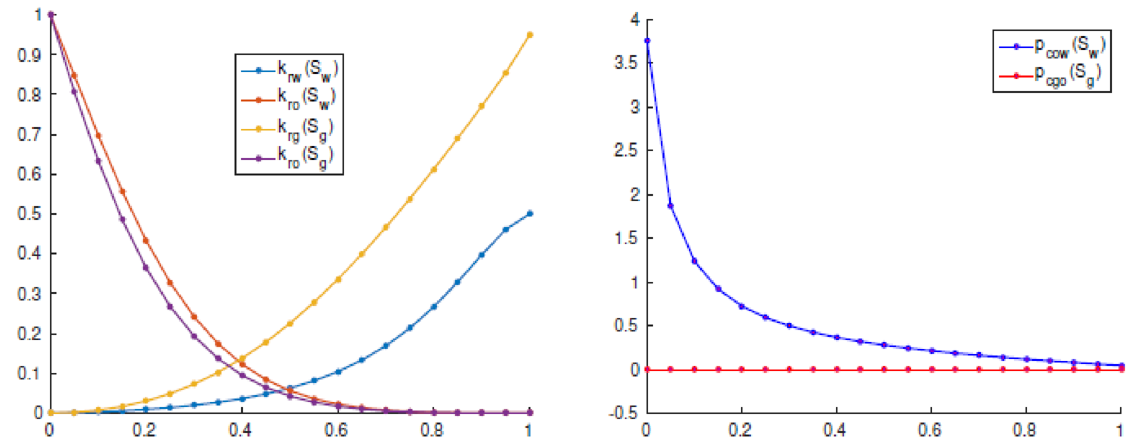


Figure 9. Flow chart to define the three phases, black oil, reservoir, surfactant and polymer models (Adapted from *Bao et al.*, 2017a)

Figures10 and 11 show examples of MATLAB generated simulation results:

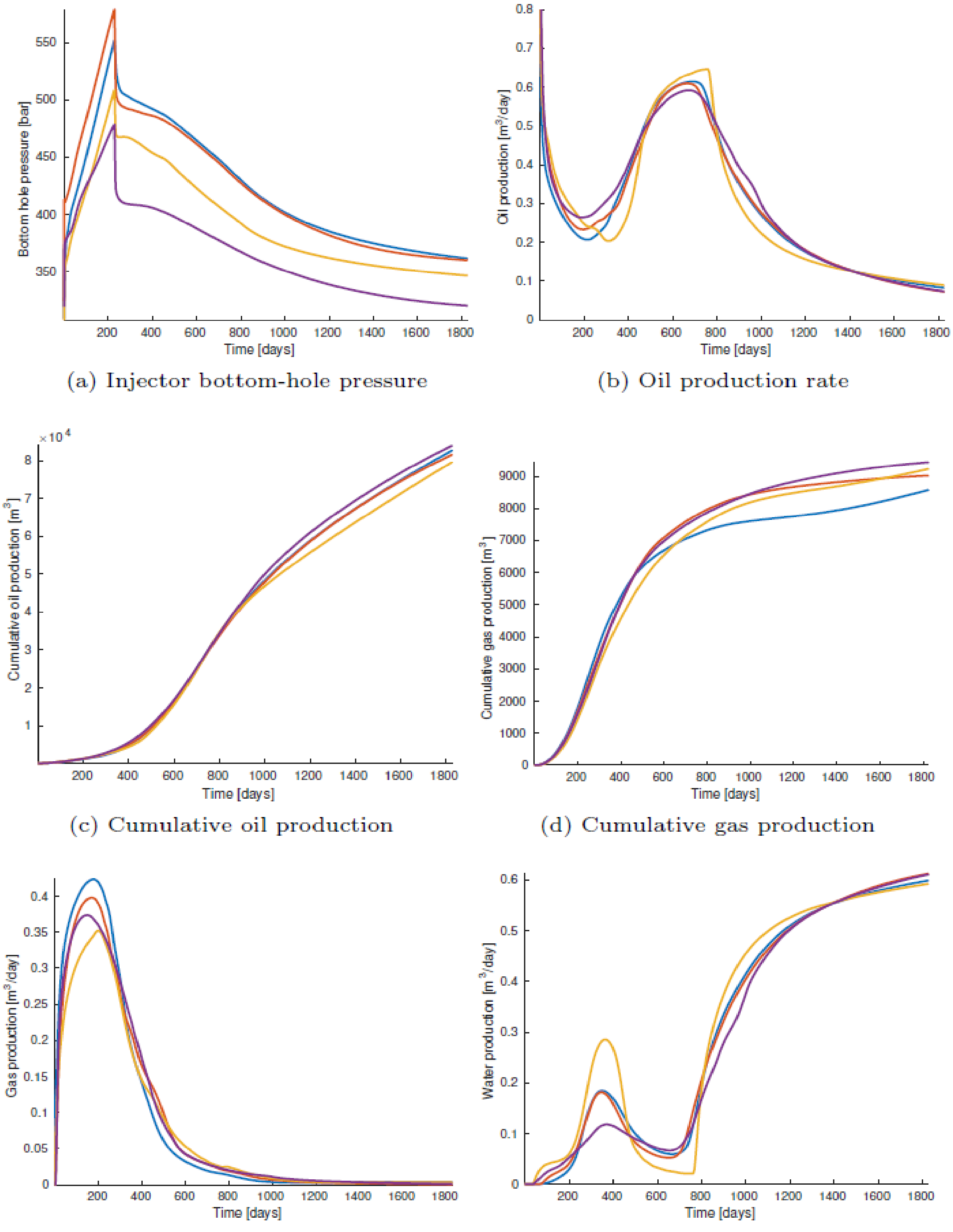


(a) Relative permeabilities (b) Capillary pressure

	Water	Oil	Gas
Surface Density	1033 kg/m^3	860 kg/m^3	0.853 kg/m^3

(c) Fluid properties

Figure 10. Example of results generated by MATLAB-MRST program in (a) to (c) (Adapted from Bao *et al.*, 2017a)



(a) Injector bottom-hole pressure (b) Oil production rate

(c) Cumulative oil production (d) Cumulative gas production

(e) Gas production rate (f) Water production rate

Figure 11. Example results generated by MATLAB program in (a) to (f) (Adapted from Bao *et al*., 2017a)

DISCUSSION

This review studied various types of lithology in reservoir rocks. However, to date only three major rock types derived from sandstone, carbonates and other (shale and conglomerate) of the 1,507 projects are currently forming the backbone of oil extraction in EOR oil fields. The extraction methods of tertiary enhanced oil recovery (EOR) have been most common by thermal (hot water injection and combustion), Gas and Chemical methods. Detailed of reservoir properties and economic considerations are of paramount importance in selection of the right type of extraction methods. Studies of rock characteristics and properties in porosity, permeability, pH, density, viscosity, temperature and pressure are the essential elements to ensure success for enhanced oil recovery in any part around the world. Shale and tight reservoir rocks formed of very low permeability and related to rock sizes and correlation of pore sizes and dependent on capillary pressure by the application of phase equilibrium equations and must be utilized to ensure accuracy in clear cut understanding of the reservoir rock condition before EOR of a certain field can be implemented.

Reservoir Simulation studies have been carried out by several researchers and further facilitate and enhance promising engagements and activities both in researches and industries. There are many types of computer software such as MATLAB-MRST and SOLIDWORKS have been developed to cater this area of necessity in EOR. Details of the MATLAB-MRST Modules have been described in Figures 8 & 9 and simulation results have shown in Figures 10 & 11. The researchers in (Li *et al.*, 2003b) have also mentioned of the superiority of the sequential solution method on black oil reservoir simulation with unstructured grids over the fully implicit solution method due to the so-called complexity of the fully implicit method and the irregularity of the grids resulted in a very complicated structure of linear equation system and of high computational cost. The sequential method could reduce the size of large linear equation system of the fully implicit method. Both methods have been applied in field scale models on saturated and under saturated reservoirs conditions and the simulation results showed that the sequential method only using of 20.1% of the computational software memory for solving linear equations and 23.89% of total computational time of fully implicit method to obtain the same precision for the under saturated reservoirs conditions when same iteration control parameters were used for both methods; but for the saturated reservoirs the sequential method need to use stricter iteration control parameters to achieve the required precision as the fully implicit method.

CONCLUSION

The EOR techniques and methods in different reservoirs rock types, conditions and the simulation methods have been discussed here thoroughly. Shale tight, sandstone, carbonates and conglomerate reservoir rock reservoirs have been reviewed with sandstone, carbonate and conglomerate rock formations. Researchers in EOR studies are still concentrating mainly and actively involving in further enhancement in development of new extraction techniques, methods and striving hard and using all efforts to find out new chemicals of environment friendly throughout the world to ensure safer and better EOR activities. Sandstone and carbonate types are being the most frequent encountered reservoir rocks and besides, methods of EOR applied are mostly thermal, gas and chemicals. These three types of EOR methods are found equally important based on material, equipment and technological know-how to date and thermal EOR method still remains top of the list and follow by gas and chemicals.

Due to the green environment requirement, it is also becoming with more essentiality, awareness and consideration to provide new environment friendly EOR extraction methods, techniques and material on this sector of industries. Researchers and oil companies worldwide are encouraged to look into all possible new methods and techniques and to comply with relevant stipulation requirement of relevant authorities worldwide to reduce great damage to mother earth.

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