ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 10 , October 2015

Reservoir Simulation for Investigating the Effect of Reservoir Pressure on Oil Recovery Factor

Saifaddeen Sallam, Mohammad Munir Ahmad, Mohamed Nasr and Sina Rezaei-Gomari

School of Science and Engineering, Teesside University, Middlesbrough, United Kingdom.
School of Science and Engineering, Teesside University, Middlesbrough, United Kingdom.
Department of Petroleum Engineering, Faculty of Engineering, Tripoli University, Tripoli, Libya.
School of Science and Engineering, Teesside University, Middlesbrough, United Kingdom.

ABSTRACT: This paper summarizes the main findings obtained from conducting reservoir simulation using ECLIPSE reservoir simulator for various oil production scenarios. These findings are important for determining and exploring the essential parameters which affect and govern the oil wells' productivity. The simulation process began by developing a reservoir model which represents an oil producing reservoir which, laterally, was used for investigating and monitoring the oil production under various circumstances. These circumstances include water flooding and changing the locations of the wells' perforations. Indeed, this part of the model development was established by running a comparative study to compare the oil production before and after the application of water injection. In the second stage of the model development, five simulation scenarios were run to monitor the oil production during the application of water injection and also when changing the locations of the wells' perforations. The results obtained so far showed good development in the oil production during the optimum application and good design of water injection projects.

KEYWORDS: ECLIPSE, Perforations, Permeability, Productivity, Recovery factor, Simulation.

I. INTRODUCTION

It has been very obvious that there is increased demand for energy consumption around the world and there is prediction of consuming the discovered petroleum reserves which are the main sources for providing the fuel to the world. Therefore, there is significant necessity for improving the recovery factor (RF) of oil from the existing petroleum reservoirs instead of producing from the newly discovered reservoirs [1]. The recovery factor (RF) refers to the total cumulative volume of the produced oil as a fraction of the initial total volume of oil in the reservoir [2]:

$$\text{Recovery Factor (RF)} = \frac{\text{Amount of the total produced oil (Np)}}{\text{Amount of Initial oil in the reservoir (OOIP)}}$$

The exploration and production of petroleum have been important issues for long time [1]. This is because of the increased demand for crude oil and natural gas which are the most known sources for providing the world's energy [3]. According to data collected form the Organisation of Petroleum Exporting Countries (OPEC) [4], there is an increased demand for the crude oil around the world as illustrated onFig. 1. Therefore, it is crucial for crude oil and natural gas producers to beconcernedabout how much of these hydrocarbons can be produced and to look for cheaper methods of producing these essential fluids without problems. Therefore, researchers in the petroleum industry are working hard to find new ideas for maintaining and enhancing the production of these hydrocarbons and to make optimum future plans to avoid any expected problems that may rise in the future and reduce the production of these hydrocarbons [5].

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 2, Issue 10 , October 2015

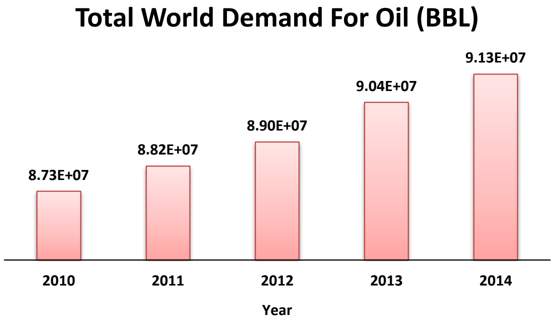

Fig. 1: Illustration of the world demand for oil.

Due to the importance of increasing the crude oil production to satisfy the demand forthe world's energy, large effort of finding out what are the problems which affect the performance of oil production wells was done. Consequently, several methods were developed to help increase the wells' production and to monitor their performance. These methods include developing new computer programs which can be used for reservoir simulation and development plans [1]. Therefore, many software programs such as ECLIPSE and Petrel [6] were developed to provide good support for forecasting and predicting the behaviour of reservoirs during the production and also during the application of Enhanced Oil Recovery (EOR) methods. In addition to that, many researches were made for predicting some rock properties such as porosity and permeability which are essential parameters for controlling the availability and movement of the hydrocarbons in the porous media (reservoir rocks) [2]. For example, there are some technical papers addressed the possibility of developing correlations for estimating and calculating the permeability of drill cuttings and reservoir rocks [7 & 8]. The main aim of undertaken these research activities and developing various software programs is to establish new modern methods for controlling and improving the traditional oil and gas production plans. The new methods should help increase the productivity of oil and gas wells without damaging the reservoir as there are some possibilities for encountering many problems which lead to declining the recovery factor of petroleum reservoirs and reduce their productivity. An example of these problems is the formation damage which occurs due to reasons such as wax precipitation, scale formation, water coning and sand movement [9]. Other problems such as reservoir fracturing, clay swelling or early water breakthrough could also be encountered during the application of Enhanced Oil Recovery (EOR) techniques [9, 10& 11]. In general, the occurrence of any of these problems will basically lead to reducing the recovery factor of production wells which means leaving large amount of oil remaining in the reservoir [12]. To find solutions to these problems, high cost requirements will be needed for increasing the production again to the required level [13]. Therefore, this research is focused at finding new solutions for avoiding any expected problems and to help produce more hydrocarbons to satisfy the increasing demand for energy. The success of this research will help reduce the cost of maintaining existing oil wells, the cost of drilling new wells and will also help save the environment from pollutants associated with drilling new wells.

II. AIM OF THE RESEARCH

There are two main aims of this research paper. The first aim is to investigate the effect of applying water injection as an EOR technique to support the average reservoir pressure and to increase the oil production. The second aim is to investigate the effect of changing the depth of the wells' perforations on the overall reservoir performance. The successes in achieving these aims should help provide good recommendations for improving the recovery of oil wells.

III. RESEARCH OBJECTIVES

There are many objectives associated with the achievement of this research's aims and which can be of great advantages to the petroleum producers. Some of these objectives are:

- Defining the parameters of the research which affect the oil production from reservoirs.
- To look out for how to control these parameters to get the best (maximum) oil production.
- To provide useful knowledge for production engineers and technicians about the research parameters.
- To explain how modifying these parameters will alter the reservoir productivity.
- To help develop good production plan that can be used for estimating the performance of oil wells and to help extend their lifecycle.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 2, Issue 10 , October 2015

IV. METHODOLOGY

The software ECLIPSE reservoir simulator [6] was chosen to build the reservoir model and to monitor its forecasted behaviour. The choice of ECLIPSE software was because it has many advantages and functions which make it featured and widely used for reservoir simulation. For example, some of this software's features are:

- Constructing different kinds of geological layers including faults and none horizontal structures.
- Estimating the direction of fluid movement and predicting water breakthrough at early stages of water injection.
- This software helps estimate the future performance of petroleum reservoirs under various circumstances by comparing the forecasted results to the actual production history.
- When developing a reservoir model using this software, new wells can be added or removed from the model to create different scenarios for determining the best production plans. This makes ECLIPSE optimumsoftware for building and developing oil production plans.

In fact, ECLIPSE has many other advantages for reservoir engineering than those mentioned here but we have only summarised those which are relevant to this research.

The procedures of building the reservoir model started by developing an input data file that can be understood by ECLIPSE software. This file contains all the required information and properties of the reservoir. For example, the model dimensions and properties of the proposed wells, which are illustrated inTable 1, were used in the input file to build the external structure of the model.The model consists of four horizontal layers where each of these layers contains 2500 cells. The model has five wells in total. One of these is a production well named PR1 whereas the others are for water injection and these are named IN1, IN2, IN3 and IN4. The PR1 well is positioned at the central point of the model whereas the rest of the wells are located at the model corners to form a five-spot water injection pattern [12] as illustrated in Fig.2.

Table 1: Physical properties of the model.

Description	Measure	Unit		Description	Measure	Unit
Total model length	10,000	**Feet**		**Number of model layers**	4	**#**
Total model width	10,000	**Feet**		**Number of production wells**	1	**#**
Total model height	200	**Feet**		**Number of injection wells**	4	**#**
Model cells length	200	**Feet**		**Max. no. of perforations in each well**	4	**#**
Model cells width	200	**Feet**		**Internal diameter of the wells**	0.6667	**Feet**
Model cells high	50	**Feet**		---	---	---
Depth from surface to top of first model's layer	8,000	**Feet**		---	---	---

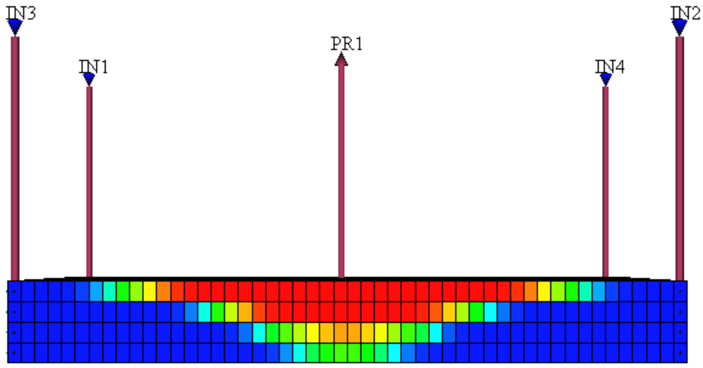

Fig.2: Side-view of the developed reservoir model (five-spot pattern).

It is assumed that the rock properties of the reservoir model would have some variations among the proposed geological layers in terms of permeability and porosity. This variation will affect the overall performance of the model when running the simulation. For example, layers which have higher permeability values are more likely to allow for higher flow rates and, consequently, these will form the suitable media for the reservoir fluids to pass through the rocks towards the production wells. The details of these properties are illustrated in Table 2.With regard to the reservoir fluids, it is proposed that the model would only have two fluids which are oil and water. These fluids will have some kind of interaction during the production process. This interaction is represented by the rocks relative permeability for the oil and water. Moreover, the wettability of the rocks to the reservoir fluids will also have strong effect on the fluid movement and may lead the water to bypass the oil towards the production well when the rocks are more oil wet.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 2, Issue 10 , October 2015

Table 2: Rock properties of the developed model.

Description	Value	Description	Value
Porosity of all layers, %	25	**Permeability of layer 3 in X-direction, md**	220
Permeability of layer 1 in X-direction, md (millidarcy)	220	**Permeability of layer 3 in Y-direction, md**	160
Permeability of layer 1 in Y-direction, md	160	**Permeability of layer 3 in Z-direction, md**	30
Permeability of layer 1 in Z-direction, md	30	**Permeability of layer 4 in X-direction, md**	220
Permeability of layer 2 in X-direction, md	800	**Permeability of layer 4 in Y-direction, md**	160
Permeability of layer 2 in Y-direction, md	400	**Permeability of layer 4 in Z-direction, md**	30
Permeability of layer 2 in Z-direction, md	120	---	---

V. RUNNING THE MODEL

The model properties presented inTable 1 and Table 2were written into an ECLIPSE DATA file using a set of keywords [6] that ECLIPSE uses for understanding and interpreting the input data and then converting it into an ECLIPSE case that can be used for simulation purposes. After preparing and gathering all the input data into the input file, a flow chart showing the plan for running the simulation was prepared as shown inFig. 3.This plan was prepared according to the aim of the research to reflect the different parameters that are going to be addressed. The plan involves running the model for various situations where, firstly, it is suggested to run the model without water injection for the purpose of monitoring the amount of the cumulative oil that can be produced naturally. Then, in the second stage of running the model, water injection was used for pressure maintaining and to enhance the production. During the second stage of running themodel there will be investigations for the best depth of the perforations' locations at the production and injection wells. The perforations, Fig.4, are small holes made into the reservoir production layers to allow the fluids to pass towards the well during production processes and into the reservoir during the injection processes[14]. Based on the assumption of changing the perforations locations, it is assumed that there are five scenarios involved in the simulation for comparing the results. The outcomes of running these scenarios will also be compared to the results obtained for running the model without the application of water injection. By the end of the simulation, the results obtained from running all of the simulation scenarios will be used for determining the best oil recovery factor and providing the required recommendations for getting the best performance in oil wells.

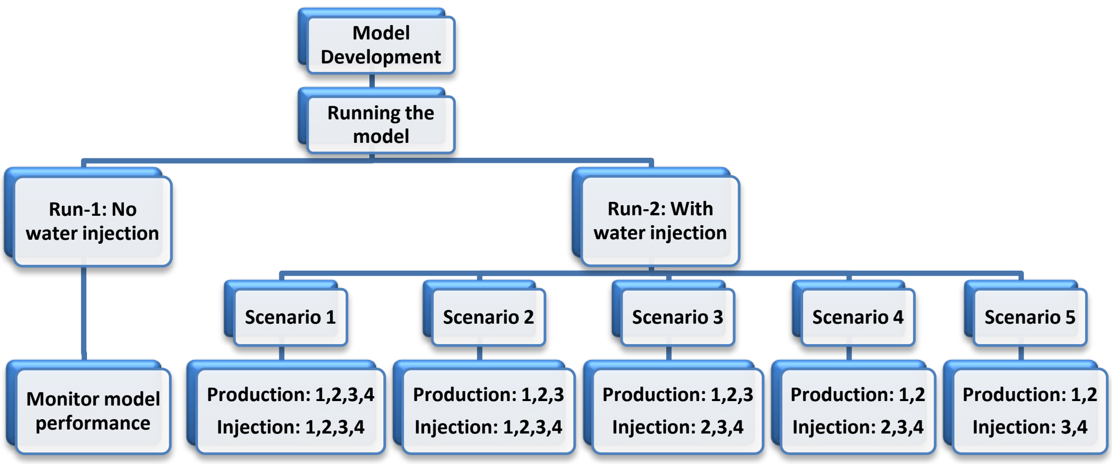

Fig. 3: Flow chart of the proposed simulation runs for the model development.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 2, Issue 10 , October 2015

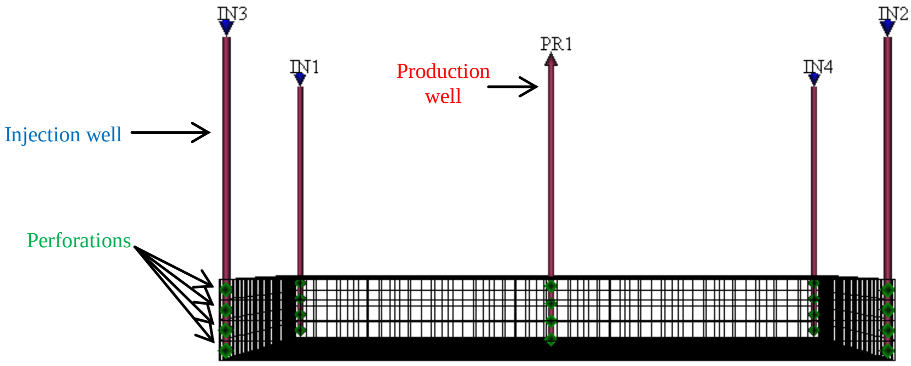

Fig.4: Perforations of the suggested wells.

VI. RESULTS OF THE SIMULATION RUNS

For the first run of the model, it was planned to monitor the production of the reservoir fluids (oil and water) under the effect of natural driving mechanism only. This mechanism depends mainly on the force generated by the initial reservoir pressure (Pi) which is directly related to the rock compressibility, the overburden pressure and the reservoir's pore pressure which is represented by expanding the compressed reservoir fluids [2]. However, the production under the effect of natural forces is expected not to last for long time because of the limited support to the initial reservoir pressure in the developed model. Indeed, in some actual reservoirs where the underneath water aquifer is very huge and the reservoir is infinite, there is continuous natural support to the reservoir initial pressure so it would not be reduced for a long time. On the other hand, when the bottom water aquifer is limited and there is no natural nor artificial support provided to enhance the average reservoir pressure, there will be declination in the production rates due to the inability for pushing the fluids towards production wells and then to the surface. Therefore, it was suggested to introduce the water injection technique to substitute the produced fluids and to maintain the average reservoir pressure at its optimum values which allow for producing more of the reservoir's oil for long duration. As planned in the research, during the application of water injection there will be some changes in the location of the wells perforations' depth to monitor the effect of this change on the recovery factor for oil and the associated/accompanied water. This monitoring was applied by running five scenarios which showed some variations in their results. These results and the results obtained before introducing water injection are presented, in more detail, in the following subsections.

A. SIMULATION RESULTS BEFORE APPLYING WATER INJECTION

When the developed reservoir model was firstly run without the application of water injection it was noticed that the average reservoir pressure was declining very quickly within few years after the start of the production as shown in Fig. 5. The oil production rate was also declining sharply from 8,996 STB/Day at the start of production to reach zero STB/Day at the end of simulation as illustrated in Fig. 6. Consequently, the cumulative oil production, Fig. 7, has only reached 27,470,436 STB out of the total original oil in the reservoir which is 617,070,590 STB. This shows that the recovery factor of the produced oil, in the first run of the simulation model, was only 4.45% out of the original oil in the reservoir. Table 3 shows a summary of these results obtained for the first run of the reservoir model.

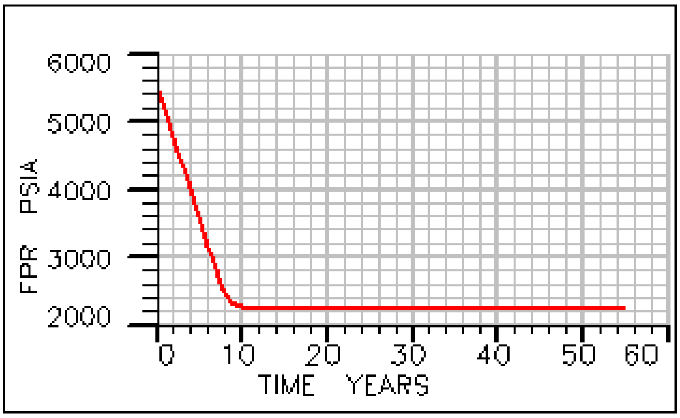

Fig. 5: Average reservoir pressure before applying water injection.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 2, Issue 10 , October 2015

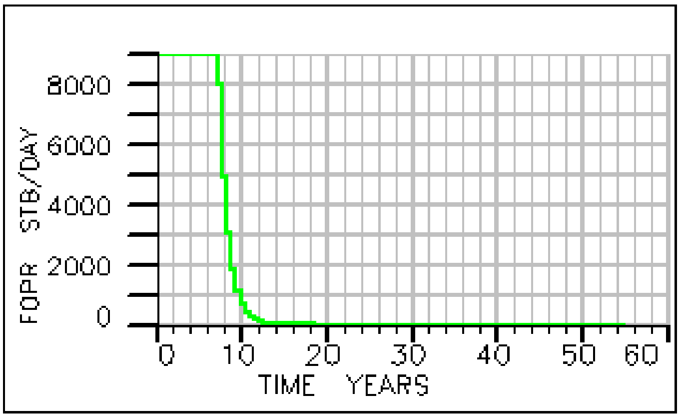

Fig. 6: Oil production before applying water injection.

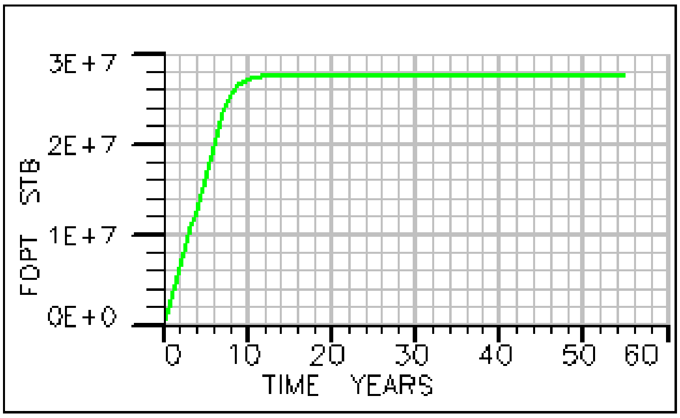

Fig. 7: Cumulative oil production before applying water injection.

Table 3: Summary of simulation results (before water injection).

Original oil in the reservoir, STB	617,070,590	**Max. reservoir pressure, PSIA**	5,506
Cumulative produced oil, STB	27,470,436	**Min. reservoir pressure, PSIA**	2,227
Max. oil production rate, STB/Day	8,996	**Oil Recovery Factor (RF), %**	4.45%
Min. oil production rate, STB/Day	0	**Cumulative produced water, STB**	85,769

B. SIMULATION RESULTS AFTER APPLYING WATER INJECTION

After the first run for the developed reservoir model where the results showed a very low recovery of oil, it was decided to run the model under the effect of water injection as planned. In this second run, five scenarios were applied to monitor the effect of water injection when changing the locations of the wells' perforations on the oil recovery factor. To do this, the locations of the perforations were set for each scenario to be open at different layers of the reservoir as illustrated in Table 4. For example, in the first scenario the production and injection were from and into the entire reservoir layers (1, 2, 3, & 4) whereas in the fourth scenario the production was only from layers (1 & 2) whereas the injection was into layers (3 & 4).

Table 4: Shows the perforations' locations in each well for each scenario.

Well Name	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
PR1	Open to layers 1,2,3,4	Open to layers 1,2,3	Open to layers 1,2,3	Open to layers 1,2	Open to layers 1,2
IN1	Open to layers 1,2,3,4	Open to layers 1,2,3,4	Open to layers 2,3,4	Open to layers 2,3,4	Open to layers 3,4
IN2	Open to layers 1,2,3,4	Open to layers 1,2,3,4	Open to layers 2,3,4	Open to layers 2,3,4	Open to layers 3,4
IN3	Open to layers 1,2,3,4	Open to layers 1,2,3,4	Open to layers 2,3,4	Open to layers 2,3,4	Open to layers 3,4
IN4	Open to layers 1,2,3,4	Open to layers 1,2,3,4	Open to layers 2,3,4	Open to layers 2,3,4	Open to layers 3,4

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 2, Issue 10 , October 2015

The outcomes of running these five scenarios showed good increase in the oil production and long term stability in the reservoir pressure. The recovery factor has increased to reach 28.70%, 28.73%, 28.73%, 28.75% & 28.80% in scenarios 1, 2, 3, 4 & 5 respectively. The highest cumulative production of oil was 177,730,210 STB obtained for the fifth scenario. It can also be seen that the amount of the produced water has also increased due to the application of water injection.However, this water will be separated in the surface production facilities and then re-injected into the reservoir to support the reservoir pressure. The results of cumulative production of oil, cumulative production of water and the oil recovery factor are presented in Table 5 and also illustrated onFig.8.

Table 5: Shows the cumulative production of oil and water for each scenario.

	Scenario-1	Scenario-2	Scenario-3	Scenario-4	Scenario-5
Cumulative Oil Production, STB	177,101,420	177,251,760	177,282,420	177,380,430	177,730,210
Cumulative Water Production, STB	2,898,572	2,748,241	2,717,579	2,619,572	2,269,787
Oil Recovery Factor (RF), %	28.70	28.73	28.73	28.75	28.80

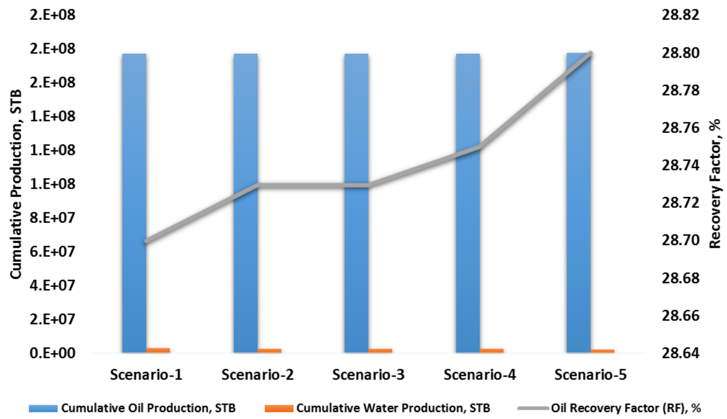

Fig.8: Summary of results obtained after water injection.

VII. CONCLUSION

Reservoir simulation is one of the most powerful techniques to estimate the reservoir behaviour under the effect of various circumstances including EOR. The results obtained for this research showed the implications of declining the average reservoir pressure and gave one of the possible solutions for preventing this decrease and allowing for long durations of oil production. Based on the results of this research, it is obvious that water injection is an adequate technique for increasing the oil recovery factor by providing and maintaining the average reservoir pressure at the optimum values which allow for pushing the reservoir oil towards the production wells. The choice of using water as an injection fluid is due to its availability in most of the oil fields either as produced water accompanying the produced oil or to be available from other sources such as sea water or salty water wells. The injection of water will help decrease polluting the surrounding environment from the chemicals found in reservoir water and, therefore, this is also an environmental protection method that helps reduce the toxic materials from being distributed on the earth's surface.

To sum with, this research has shown a positive increase for the recovery factor results where this was increased from 4.45% in the first simulation run to reach 28.80% in scenario five of the second simulation run. This increase in the oil recovery factor resulted in producing an additional 150,259,774 STB above the oil production that was produced before the application of water injection. Therefore, it is recommended that water injection is an adequate method for enhancing oil production. However, there are many factors should be taken into account when designing water injection projects. These factors can be adjusted and controlled through the proper planning and good estimations for the future performance of the reservoir.

For future research, it is aimed to have more simulation scenarios with different production circumstances as we have seen here the effect of changing the locations of the perforations did not show significant change in oil recovery factor; therefore, re-running the simulation for other oil production scenarios under the effect of different parameters is going to take place in the future research.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 2, Issue 10 , October 2015

REFERENCES

[1] Sallam, S., Ahmad, M.M., and Nasr, M. (2014). "Development of Predictive Production Model for Increasing Productivity of Oil Wells". The 24th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM), May 20-23, 2014, San Antonio, Texas, USA.
[2] Ahmed, T. (2010). Reservoir Engineering Hand Book. 4th Ed. Elsevier: Oxford.
[3] Lucky M. & Rogers, R. (2013). Oil is Still World's Largest Energy Source, But Coal and Natural Gas are Gaining. Web article published by Environmental News Network (ENN) at: (http://www.enn.com/environmental_policy/article/45420). Last accessed: 04/12/2014.
[4] Organization of Petroleum ExportingCountries(OPEC), (2015). Annual Statistical Bulletin (ASB) 2015. Available from: (http://www.opec.org). Last accessed: 15/10/2015.
[5] Sallam, S., Ahmad, M.M., and Nasr, M. (2014). "Predictive Production Modelling for Increasing Productivity of Oil Wells". The First Libyan Higher Education Forum: A Vision to the Future. June 05-07, 2014, London, UK.
[6] Schlumberger (2011), Schlumberger Simulation Launcher, Version 2011.2.
[7] Sallam, S. and Ahmed, H. (2010). "A trial of correlating rock permeability to other petrophysical rock properties". 1st Basra international oil and gas conference, Basra, Iraq, 26-27 November, 2010.
[8] Sallam, S. and Ahmed, H. (2011). "A modified correlation for calculating Klinkenberg permeability". The 2nd Basra international oil and gas conference and exhibition, 25-28 November 2011, Basra, Iraq.
[9] Dandekar, A.Y. (2006). Petroleum Reservoir Rock and Fluid Properties. CRC Press: US.
[10] Dake, L.P. (1978). Fundamentals of Reservoir Engineering. Elsevier: The Netherlands.
[11] Tiab, D. and Donaldson E.C. (2003). Petrophysics: Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties. Second Edition. Elsevier: Oxford.
[12] Alvarado, V. and Manrique, E. (2010). Enhanced Oil Recovery. Golf Professional Publishing: Oxford.
[13] Sallam, S., Ahmad, M.M., and Nasr, M. (2015). "The Effect of Water Injection on the Oil Well Productivity". The 25th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM), June 23-26, 2015, University of Wolverhampton, Wolverhampton, UK.
[14] Bellarby, J. (2009). Well Completion Design. Elsevier: the Netherlands.

NOMENCLATURE

STB	: Stock Tank Barrel.
FPR	: Field Pressure (Average reservoir pressure).
FOPR	: Field Oil Production Rate.
FOPT	: Field Oil Production Total.
RF	: Recovery Factor.