Development of Predictive Production Model for Increasing Productivity of Oil Wells

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Abstract

This paper highlights some of the reasons for the oil production decline in petroleum wells and underlies principles to produce a new model for the oil wells' production performance. The research starts by introducing some information about the available world energy resources which shows that petroleum and natural gas are used more than any other energy sources. The research also presents further information about the productivity index of oil producing wells and their performance including how this is affected and how it can be enhanced using different available methods. The total world oil reserves, gap in production and demand and how this research is important for increasing the oil production is explained. The analysis shows that a 15.47% increase in the oil reserves between the years 2008 and 2012 had caused the total world oil reserves to increase from 1,280,114 million barrels in 2008 to reach 1,478,211 million barrels in 2012. The research has showed that the additional 198,097 million barrels are sufficient to cover the world's demand for oil for about six years based on the rate of oil demand in 2012 of 32,459 million barrels. However, the total world's oil production in 2012 is 26,611 million barrels which is not enough to meet the demand. Therefore, the aim of this research is to find suitable methods for producing oil from the available oil reserves to cover the demand by reducing the losses in the oil producing wells rather than depleting the newly found reserves. However, this research is still ongoing and it is expected to give more interesting and valuable results in the future.

1. Introduction

There are many difficulties encountered by oil production companies during the production of oil which lead to losses and decline in oil output. Some of these difficulties include formation damage and early water production which cause the ratio of water to oil production to rise at an early stage of the production. These problems lead to a decline in oil production and lower the performance of the well if not solved properly. The purpose of this research is to develop a production model which will enable a prediction of the oil production from the oil wells by early identification of the causes of the losses and taking remedial actions. The model will help in the primary identification of the reasons for production decline and assist in maintaining and enhancing the production output. Moreover, it will also help in improving the production rate and enhance the output by reducing the quantity of the residual oil in oil wells.

The exploration and production of petroleum have been important issues for a long time. This is because oil and natural gas are considered to be the most demandable world energy resources [1]. According to data gathered from the Energy Information Administration (EIA) [2], oil and natural gas represent 37% and 26% of the world energy consumption respectively as illustrated in figure 1. Therefore, petroleum production companies are concerned with how much of these energy resources can be produced. Consequently, it was important for petroleum producers to work harder to maintain the optimum production of these resources and to investigate any existing or expected problems which lead to decreasing or stopping their production.

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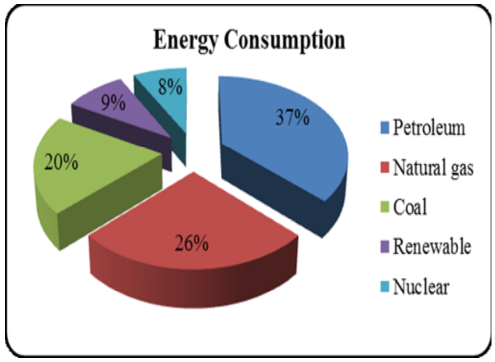

Figure 1. Illustration of the world energy consumption, (a reproduced image [2]).

2. Literature Review and Justification of Research Problem

There are many problems which lead to petroleum production decline. These problems include formation damage which happens in reservoirs as a result of many reasons such as wax precipitation, scale formation, water coning and fine migration [3]. Other problems may also occur during the application of Enhanced Oil Recovery (EOR) techniques where different fluids are injected into the reservoir [4]. Some of the problems which occur during EOR applications include, reservoir fracturing and reservoir collapsing which may happen as result of generating a very high pressure in the injected area of the reservoir [5]. Moreover, pore blockage and permeability reduction may also happen because of sand movement, clay swelling and chemical reactions due to incompatibility between the injected materials and either the reservoir rocks or the original reservoir fluids [3]. Another problem could be the early water breakthrough where the injected water bypasses the oil towards the production wells due to reasons of wettability and capillary pressure [6]. Such these problems will lead to oil production decline by reducing or closing the reservoir pores which allow the fluids (oil, gas and water) to flow towards the producing wells.

There are many early precautions for avoiding and monitoring oil production decline problems. For example, petroleum specialists use the productivity index which refers to the ability of reservoirs to produce oil at a chosen flow rate when a specific reservoir pressure is applicable to monitor oil and gas production rates [7]. The productivity index is defined by the following equation:

$$J = Q_o / (P_r - P_{wf}) \quad (1)$$

where, J= productivity index (BBL/Day/Psi), Q_o= oil flow rate (BBL/Day), P_r= average reservoir pressure (Psi) and P_{wf}= the bottom well flowing pressure (Psi).

According to Dandekar [3], there are different types of oil reservoirs where oil is generated and stored before it is produced. The production of oil from these reservoirs is affected by the type of rocks which form each reservoir. Indeed, these reservoirs can either be heterogeneous or homogeneous according to the primary formation of the earth layers. These reservoirs are classified into two main groups according to their type:

- Sandstone Reservoirs: this type of oil reservoir is formed from small particles of sand bonded together by melting materials such as clays to form the sandstone rocks [7]. The permeability of sandstone rocks vary according to the structure of the rock. Some sandstone formations could have as high permeability as 1000 millidarcy (md) or more whereas other formations could have as low permeability as 0.1 md or less [5].
- Carbonate Reservoirs: this type of reservoir, also known as limestone reservoirs, has very low permeability and high sensitivity to water. Carbonate reservoirs are more likely to have problems than sandstone reservoirs and, therefore, it need more care when dealing with it [3].

The natural production of oil from these reservoirs is related to many factors. The most important factor is the average initial reservoir pressure (Pi) which when it decreases, other secondary production mechanisms (i.e. EOR) will have to be introduced [4]. According to Lyons and Plisga [8], it is very important when applying EOR techniques to have some knowledge about the type of formation which will be treated as wrong input data will lead to unexpected results. The reservoir initial pressure is mainly related to parameters such as the depth, the size of the reservoir and the initial driving mechanism which can be water or gas [4]. The other factors which also affect the natural production of oil are permeability and porosity of rocks, viscosity and density of oil which are also related to other factors such as reservoir temperature and pressure [4].

The permeability of rock is an important parameter during oil production as it refers to the ability of rock to pass the fluids through its pore spaces [9]. The permeability is an important petrophysical rock property for controlling petroleum production. Therefore, this parameter has been under investigation by many researchers for a long time either by conducting some experimental work using uniform core samples or by the use of drill cuttings which are collected during drilling operations. According to Fens et al. [10], many researchers carried out their studies with the aim of predicting petrophysical rock properties from small size core samples such as sidewall samples and drill cuttings. The main drive for these studies was the increasing number of deep exploration prospects which face harsh circumstances such as high pressure and temperature where obtaining core samples for lab analysis is difficult and expensive. In addition, the concentration on investigating rock permeability has been very important for getting information about the maximum possible flow which means producing more petroleum with fewer problems. One of the famous correlations for estimating rock permeability from drill cuttings was modified by Timur [11] for the North American oil fields. Timur [11] looked at the use of drill cuttings as these are collected regularly while drilling the wells and their properties of porosity and fluid saturation can easily be measured. Timur [11] developed his correlation for estimating rock permeability of these cuttings when their porosity and initial water saturation are known in the following form:

$$k = 0.136 \times \emptyset^{4.4} / (S_{wi})^{2} \qquad (2)$$

where, k= permeability (md), Ø= porosity (%) of bulk volume, and S_{wi}= initial water saturation (%) of pore volume.

Other researchers such as Baptist and Sweeney [12] conducted a series of experimental work on core samples to examine whether rock permeability changes or not when injecting waters of different salinities through core samples that contain different amounts of clays. A more recent research by Abbasi et al. [13] investigated what types of clay minerals could reduce the permeability of rocks and block the pore spaces when injecting waters of different salinities to the rock samples. Their research was mainly to gain knowledge about the sensitivity of different types of clays to changes in water salinity. However, none of the previously two mentioned researches produced any correlation for estimating rock permeability.

Therefore, this research is aimed to continue the investigations about the performance of oil producing wells and how the permeability of rocks to the different kinds of hydrocarbons is affected before and after the application of EOR using the water injection technique. The new ideas in this research include correlating rock permeability to water injection parameters and to the rock and reservoir fluid parameters taking into account all the affecting factors such as water salinity, reservoir pressure and oil viscosity.

3. Objectives of The Research

Permeability is the main factor which controls fluid flow in porous media (rocks). The alteration of this parameter could affect the productivity of the oil wells either positively or negatively. For example, when the permeability of rocks increases this will result in more oil production as the pores of the reservoir rocks become larger allowing higher flow rate of fluids. Therefore, the objectives of this research are summarized as follow:

- Develop an oil production model that can be applied in the oil industry for determining the optimum oil production parameters and to find out what factors that affect the permeability of rocks and how to minimize the damage of their effect on the reservoir.
- Increase the knowledge of petroleum engineers about the effect of using different ranges of water salinities on the different types of reservoir rocks as this will lead to minimizing the risk of damaging petroleum reservoirs during the application of water injection.
- Help in estimating the future oil production performance of oil wells and determine the affecting parameters which enhance their productivity.
- Provide an optimum oil production plan that takes into account any parameters which may affect the reservoir rock and fluid properties. This plan should also help in avoiding the expected risks and will help increase the well productivity.

4. Identifying The Problem of Production Decline

The problem of oil production decline may happen at any stage of the production if any of the causing reasons is available. This problem is usually monitored by recording the oil flow rate at the head of the well [14]. However, there are many well testing methods are used to identify and confirm the reasons of the decline. These methods include, but not limited to, the following:

- Pressure survey test: this method is used to monitor the average reservoir pressure using different tools which are fitted into the bottom of the well to record the pressure history of each well [15].
- Formation damage test: this is usually done by the use of pressure build-up and draw-down tests. These tests determine whether the reservoir is damaged or not where the damage is reflected by a decrease in the average reservoir permeability [16].
- Water coning test: this happens when the bottom reservoir water starts to cone around the wellbore. This can be identified by monitoring the increased amount of the produced water and decreasing the oil production rate which result in high water cut ratio [7].

5. Results And Discussion

According to the data presented in table 1 which was gathered from the Annual Statistics Bulletin (ASB) published by the Organization of Petroleum Exporting Countries (OPEC) [17], the total petroleum reserve has increased over the last few years for the total world from 1,280,114 million barrels in 2008 to reach 1,478,211 million barrels in 2012 as illustrated in figure 2.

Table 1. Shows data of the total world oil reserve, production and demand.

Year	2008	2009	2010	2011	2012
Total world Reserves, million barrels	1,280,114	1,324,980	1,457,983	1,465,556	1,478,211
Total world Production, 1000 barrels/day	71,823.4	68,965.6	69,888.3	70,460.9	72,858.6
Total world Demand, 1000 barrels/day	86,067.9	84,780.4	87,187.2	88,103.8	88,868.5

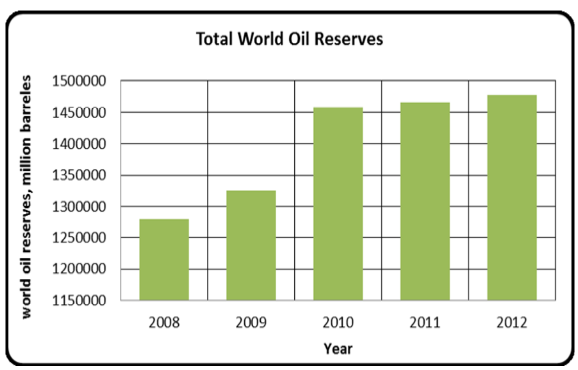

Figure 2. Shows the total world oil reserve between 2008 & 2012.

The data presented in table 1 was used to run some useful calculations which are presented in table 2 on the next page. The calculations show that the additional oil reserves of 198,097 million barrels of oil in 2012 represents 15.47% comparing to the data of oil reserves in 2008. This increase is sufficient to cover the world demand of crude oil for about six years based on the crude oil demand in 2012. Therefore, the achievement of the aims and objectives of this research is expected to be a successful step towards producing more of the available oil which helps to provide more oil for the total world in general and, moreover, to increase the financial income of many oil producing countries in particular.

Table 2. Shows some useful calculatitions using the data of oil reserve and demand.

Increase in crude oil reserves between 2008 and 2012	198,097	million barrels
% of increase comparing to 2008	15.47	%
Annual increase (over 4 years)	49,524	million barrels
Total world crude oil demand in 2012	88,868,500	Barrels/Day
Total world crude oil demand in 2012	32,459,219,625	Barrels/Year
Total world crude oil additional reserves in 2012	1.98097E+11	Barrels
Additional years recovered by the additional reserves	6.1	Years

However, the data of the total world oil production and demand between the years 2008 and 2012 shows that there is a shortfall in the oil supply which is needed to meet the world's oil demand as illustrated in figure 3. Therefore, it is important to modify new methods that can be used to produce the available oil reserves without problems.

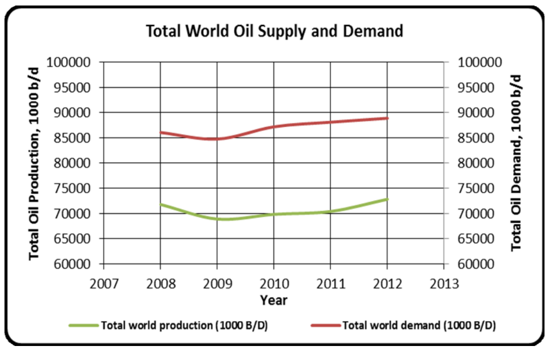

Figure 3. Shows the total world production and demand of oil between 2008 & 2012.

A further data of oil production history was collected for an oil well in Libya for investigating the preliminary relationship between some parameters such as oil, gas and water production flow rates. For doing this, a simple three dimensional model was plotted using DataFit software for the collected production data. The obtained graph shows smooth data plotting as presented in figure 4 where the coefficient of multiple determinations, R^2, is 0.99261. The correlation between the three parameters is represented by equation 3 as follow:

$$Y=a*(X_1)^\wedge b*C^\wedge X_2 \tag{3}$$

where, Y = oil production rate, BBL/Day , X_1 = water production rate, BBL/Day, X_2 = gas production rate, SCF/Day and a, b, c = regression parameters:

Parameter	Value
a	1289.84
b	-0.6196
c	1.01234

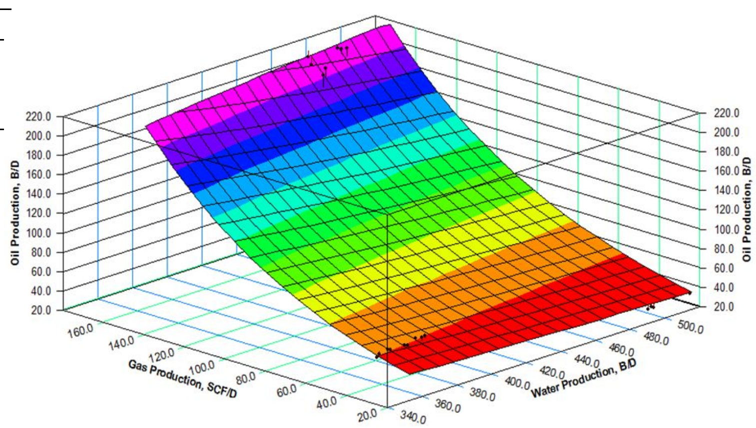

Figure 4. Illustrates the three dimensional relationship between oil, gas and water production rates for an example well.

A further data, presented in table 3, was collected for permeability of rocks to waters of different salinities from Baptist and Sweeney [12]. This data was plotted on figure 5 to investigate the change in rocks' permeability to the flow of water when changing its salinity from 16,500 ppm to 8,250 ppm to 0 ppm. It was noticed that some of the samples were very sensitive to the change in water salinity as their pores were completely blocked when injecting fresh water whereas other samples were less affected by the salinity change. This alteration in permeability occurred as a result of clay swelling and fine migration which happened when injecting waters of different salinities to the samples. However, the graph shows that the permeability of samples is proportionally related to the change in the injected water's salinity. Therefore, there is possibility of finding a correlation which represents this relationship; however, this will require more data of permeability to waters of different salinities and also data of the composition of the used rock samples.

Table 3. Shows the collected data for permeability to waters of different salinities.

Sample	k_{a1}	k_{b1}	k_{b2}	k_w	k_{af}	Kaolins	Illites	Mixed layer
#	md	md	md	md	md	%	%	%
A	27	4.05	0.27	0	24.03	10.8	18.9	70.3
B	76	16.72	13.68	6.08	51.68	44.4	13.9	41.7
C	52	33.28	33.28	9.88	59.8	50.0	50.0	0.0
D	46	45.54	45.08	33.12	46	37.5	62.5	0.0

where, k_{a1}: is the initial sample permeability to air in millidarcy, md.

k_{b1}: is the sample permeability to the water of salinity 16,500 ppm.

k_{b2} : is the sample permeability to the water of salinity 8,250 ppm.

k_w : is the sample permeability to fresh water, md.

k_{af} : is the final sample permeability to air, md.

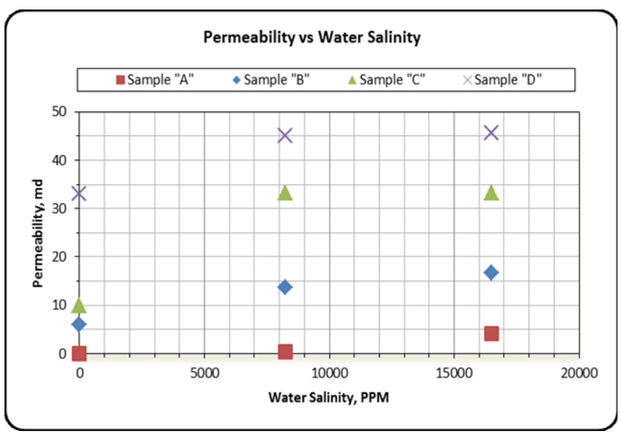

Figure 5. Illustrates how rock permeability changes according to change in water salinity.

6. Recommendations For Better Performance In Oil Wells

According to Alvadrado and Manrique [6], there are many methods such as enhanced oil recovery (EOR) and well stimulation techniques can be used for increasing oil wells productivity and performance. However, the measurement of a process performance which leads to a world-class performance excellence requires good knowledge about the framework of that process [18]. Therefore, in the case of petroleum engineering, it is essential to benefit from the existent experience in the petroleum industry and to think about the parameters which enhance the well performance and increase the oil production and how to properly have a good preparation of these parameters from the very early time of the well age. Thus, the parameters which control the performance of the well can be divided into two main groups. The first group represents the parameters which have to be controlled before drilling the well whereas the other group represents the parameters which occur at later stages of the well production. These two groups are described in more details as follow:

1) Primary well performance parameters

When looking at the oil well from theoretical point of view, it can be seen that it looks like a manufacturing plant; it needs good input parameters in order to give good production. In fact, there are four main input parameters which have to perfectly be prepared and applied in order to achieve good well productivity. These parameters include well planning, well drilling, well preparation and well completion. The application of these parameters needs good experience because any errors at this stage will lead to unexpected future performance which may include financial losses and worse production than expectations. Therefore, for an effective oil well performance, achieving the aim of gaining good oil production requires the good choice and application of the essential input parameters which can be summarized as follow:

- Well planning: this includes the choice of the well location which is very important and it has to carefully be planned in accordance to geological data which is supplied by geoscientists before the start of the well drilling. Wrong well location data could result in large financial losses which cannot be recovered if the well appeared to be dry.
- Well drilling: there are different varieties of drilling tools which include different types of drilling bits and pipes have to carefully be chosen. The choice of each of these depends on some parameters which include the type of the drilled formation, the depth and the required penetration rate.
- Well preparation: this includes operations such as well cleaning, cementation and perforation. These operations are used to prepare and clean the well hole from drilling cuts and fluids which are used during the well drilling. The well cementation is used to support the well's wall and prevent it from collapsing. The layer of cement is perforated to allow oil production from the chosen productive formations. The good preparation of the well for production plays a good role for extending the lifecycle of the well for many years.
- Well completion: this process include techniques such as well acidizing and formation fracturing. These operations have to perfectly be conducted as any errors could damage the well badly. For example, when poor acidizing process is applied, the area around the well bottom will not be cleaned as required causing undesirable results which lead to blocking the formation channels and prevent the production. Therefore, good well completion leads to good well production.

2) Secondary well performance parameters:

There are many parameters which appear after duration of the well production and, if not controlled properly, it will lead to decreasing the oil production. These parameters include:

- Low reservoir pressure: the pressure of the reservoir will start to decrease after a period of production because of the depletion. This will cause the production to decrease as the pressure is considered to be the main driving force which enables the natural oil production.
- Low permeability: early production decline is more likely to occur in naturally low permeability reservoirs at earlier time than in high permeability reservoirs. This is because the narrow rock pores are more likely to be blocked as a result of fine sand migration and precipitations of wax and salts which prevent the fluids from flowing towards the production wells.
- Formation damage: this is a major problem in oil wells. It happens as a result of many reasons which include scale precipitation, wax formation, sand movement, formation collapsing and water coning. All these problems lead to blocking the reservoir channels which transmit oil towards the production wells.
- Water coning: this problem happens when the bottom reservoir water starts moving towards the production wells. This can happen as a consequence of many reasons which include producing oil at higher flow rate than the optimum where this alters the capillary forces between water, oil and rocks. Also, the wrong location of perforations leads to early water breakthrough specially when perforating near the water zone. Water coning prevents the oil from being produced because water blocks the pore channels and prevents the movement of oil towards the production wells.

7. CONCLUSION

In conclusion, this paper has summarized some of the main research findings and recommendations about the causes and effects of oil production decline and the possible early solutions for this problem. The following is a summary of the main key conclusions of this work:

- This research is very important and can be beneficial for the petroleum industry as it investigates the causes and effects of oil production decline in oil wells.
- The research has presented some information about the improvements of well performance and explained the main reasons of oil production decline. The research has also presented some calculations related to the oil reserve and demand and showed that an increase in the world oil reserve by 15.47% is sufficient to cover the total world demand for crude oil for about six years.
- The research has showed that good future performance of oil wells requires good initial planning which has to begin from the moment of choosing the location of the well. Also, the parameters which affect the well performance before and after the well drilling should be taking into account and perfectly controlled.
- The research has also presented a simple correlation for calculating the oil production rate when the gas and water flow rates are known. Additionally, the research shows that the permeability of rocks is proportionally related to the salinity of the injected water.

REFERENCES

[1] M. Lucky & R. Rogers: "Oil is Still World's Largest Energy Source, But Coal and Natural Gas are Gaining". Web article published by Environmental News Network (ENN), available at: www.enn.org (Last accessed: 10/11/2013), 2013.

[2] Energy Information Administration, EIA: "Annual Energy Review, (AER), 2011", Web document, available at: www.eia.gov (Last accessed: 06/11/2013), (2012).

[3] A. Y. Dandekar: "Petroleum Reservoir Rock and Fluid Properties", CRC Press: US, 2006.

[4] L. P. Dake: "Fundamentals of Reservoir Engineering", Elsevier, the Netherlands, 1978.

[5] D. Tiab and E.C. Donaldson: "Petrophysics: Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties", Second Edition, Elsevier, Oxford, 2003.

[6] V. Alvarado and E. Manrique: "Enhanced Oil Recovery", Golf Professional Publishing, Oxford, 2010.

[7] T. Ahmed: "Reservoir Engineering Hand Book", Fourth Edition, Elsevier, Oxford, 2010.

[8] W.C. Lyons and G.J. Plisga (Ed):"Standard Handbook of Petroleum and Natural Gas Engineering", Second Edition, Elsevier, Oxford, 2005.

[9] D. Tiab and E.C. Donaldson: "Petrophysics: Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties", Third Edition, Elsevier, Oxford, 2012.

[10] T.W. Fens, M.A. Kraaijveld, L. Riepe and R. Visse: "Archie's Dream: Petrophysics from Sidewall Samples and Cuttings", Society of Core Analysts (SCA), Paper: SCA1998-05, available at: www.scaweb.org, (Last accessed: 19/02/2014), 1998.

[11] A. Timur: "An Investigation of Permeability, Porosity and Residual Water Saturation Relationships", Society of Petrophysicists & Well Log Analysts, SPWLA 9th Annual Logging Symposium, New Orleans, Louisiana, 1968.

[12] O. C. Baptist and S. A. Sweeney: "The Effect of Clays on the Permeability of Reservoir Sands to Waters of Different Saline Contents", Bureau of Mines, US, 1954.

[13] S. Abbasi, A. Shadrabadi and H. Goghanddashti: "Experimental Investigation of Clay Minerals' Effects on the Permeability Reduction in Water Injection Process in the Oil Fields", SPE European Formation Damage Conference, Noordwijk, the Netherlands, 2011.

[14] J. Bellarby: "Well Completion Design" Elsevier, the Netherlands, 2009.

[15] Schulmberger (SLB): "Fundamental of Formation Testing", Web document available at: www.slb.com, Schulmberger, (Last accessed: 10/11/2013), 2006.

[16] A. U. Chaudhry: "Oil Well Testing Handbook", Elsevier, Oxford, 2004.

[17] Organization of Petroleum Exporting Countries (OPEC): "Annual Statistical Bulletin", web document available at: www.opec.org, OPEC, (Last accessed: 03/10/2013), 2013.

[18] M. Ahmad and R. Benson: "Benchmarking in the process industries", Institute of Chemical Engineering, Warwickshire, UK, 1999.