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Integration of Technical Problems and Diagnosis of High Water Cut - Sudanese Oil Fields Case

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ABSTRACT:

This paper discusses various aspects of technology relative to control the excess water production in oil fields. It covered the understanding of the water production mechanism which causes water production problems; and it focused on the way of diagnosing the problems of excess water production. The diagnostic plots derivative technique was discovered based on systematic numerical simulation studies especially on reservoir water coning and channeling. Concerning the application of the diagnostic plots the paper provided a simplified computation and quick technique for engineers, by using Microsoft Excel format on calculating and plotting the derivative response, considering two case examples of a Sudanese oil well's data, verification made by comparison result with standard diagnostic plot of Chan. This paper is an integrated technical guide for researchers, geologists and petroleum engineers especially the reservoir engineers on diagnosis of a high water cut problem, which has become a severe problem in the Sudanese oil fields.

KEYWORDS: *water production problems, diagnostic plots derivative technique, diagnostic plot of Chan.*

INTRODUCTION

Since 2003 most of the water flooded Sudanese oil fields gradually stepped into the stages of moderate and high water cut. The previous technologies for early development stage of oil fields are no longer suitable for the present oil fields development. It is critical and key technical problem to develop a new improved water flooding technology to stabilize and increase crude oil production in developed oil fields. Excess water production represents difficult operational problems for all reservoirs producing by dominate mechanism of bottom water drive.

The main target of improved water flooding technologies is to increase the sweep efficiency and fluid production rate, extend the stable oil production period and select a proper methodology for increasing the oil recovery efficiency.

A high water cut water flooded reservoir is one of the major economical, technical, and environmental problems associated with oil and gas production. Excess water production limits the productive life of oil and gas wells and causes severe problems including corrosion of tubular, fines migration, and hydrostatic loading.

Too high production rate may result in quick water coning and fast water fingering, which lower down the efficiency of water displacement, hence reducing the cumulative oil production.

Sharp water coning shape, if formed in most well, in such a short period of development, means large quantity of by passed oil is left undeveloped; and will complicate the oil/water distribution in the reservoir for further Enhanced Oil Recovery (EOR).

The Problems of Excess Water Production (High water Cut):

Once the water production mechanism is understood, an effective strategy can be formulated to control water production [(1)]. Therefore it is very important for engineers to identify exactly the problem which causes high water cut production

Reservoir Porous Media Problem

The sources of produced water include formation water, aquifer, and injected water. The formation water may originate from a water saturated zone within the reservoir or zones above or below the pay zone. Many Sudanese reservoirs are adjacent to an active aquifer and are subject to bottom or edge water drive. Water is often injected into oil reservoirs for pressure maintenance or secondary recovery purposes; this injected water is one of sources of water production problem.

The water flooded reservoir development problem

A major problem occurs when the reservoirs enter the super high water cut stage; therefore, it is more complicated and difficult stage of reservoir development. The difficulties can be explained considering the following issues i) the injection-production system is not in a perfect relationship, ii) a high ratio of the numbers of production/ injection wells which needs to be adjusted in a suitable value, ii) low degrees of monitoring and control of water flooding, v) an unbalanced reservoirs internal pressure, is a high pressure difference between different layers and reservoir blocks, vi) a low water flooding efficiency, and vii) a large number of wells with casing damage.

High permeability streak problem

In water-drive reservoirs and reservoir that are subjected to water flooding, reservoir heterogeneity can result in water channeling through high permeability streaks; oil, gas, and water flow mainly along the path of least resistance, which are usually the higher permeability parts of the reservoir.

Unfavorable mobility ratio problem

The unfavorable mobility ratio could potentially be considered a major factor in increasing the excess water production due to low viscosity of the aquifer water compared to high viscosity of heavy and medium heavy oil this leads to premature water breakthrough due to a fingering phenomenon. Several Sudanese oil fields of heavy and medium heavy crude oil are attached to a very active water aquifer; therefore these oil fields are suffering excess water production.

Fissures or Fractures

Natural fracture zones or when wells are hydraulic fractured, the fracture often unintentionally breaks into water zones [(2)].In such cases, coning through hydraulic fracture can result in substantial increase in water production In addition, stimulation treatments can cause barriers breakdown near the wellbore often, impermeable barriers (e.g., shale or anhydrite) separate hydrocarbon-bearing strata from water saturated zone that could be the source of the excess water production

In unfractured reservoirs often stratification and associated permeability variations among various layers can result in channeling between an injector and a producer or from an edge water aquifer to the producers [(3)].

Water Coning Problem

Water coning is caused by vertical pressure gradient near the well. The well is produced so rapidly that viscous forces overcome gravity forces and draw the water from a lower connected zone toward the wellbore [(3)]. Eventually, the water can break through into the perforated or open-hole section, replacing all or part of the hydrocarbon production. Once a breakthrough occurs, the problem tends to get worse, as higher cuts of the water are produced.

Vugs and Faults

Deviated and horizontal wells are prone to intersect faults or fractures. If these faults or fractures connect to an aquifer, water production can jeopardize the well [1].

Well Problems:

As previously mentioned excess water production is one of the major technical, environmental and economical problems associated with oil and gas wells production, it is always a challenging task for field operators the cost of handling and disposing produced water can significantly limit the economic producing life of the well, and can cause severe problems including tubular corrosion, fines migration, and hydrostatic pressure created by high fluid levels in the well. The latter is detrimental to oil production.

Well integrity Problem

Well integrity is application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well [4].There are various facets to well integrity, includingaccountability/responsibility, well operating processes, well service processes, tubing/annulus integrity, and tree/wellhead integrity and testing of safety systems. Confusion regarding the definition of well integrity can make it difficult to create a holistic approach to implementing a management system, Joe [5] defines "Well Integrity" and presents the framework used by British Petroleum to implement and manage well integrity system.

Casing/tubing leak, packer leak Problem

The common completion related problems are channel behind casing, completion into or close to water zone, completion into the zones where water saturation is higher than the irreducible water saturation allows the water to be produced immediately

Casing leak results in unwanted entry of water and unexpected rise in water production, often casing leaks occur where there is no cement behind the casing [6] .

Cement channel Problem

Channels behind casing can result from poor cement-casing or cement-formation Bonds [6]. Channels behind casing can develop throughout the life of a well, but are most likely to occur immediately after the well is completed or stimulated.

Methods of Diagnosing Problems:

Various tools and technologies are available in oil industry for controlling undesirable water production, each of these technologies has been developed for certain types of water production problems, whereas appropriate selection of the water control technology depends on the correct identification and diagnosis of the water production problem source. Hence water production problems often are not properly diagnosed. In fact, incorrect, inadequate, or lack of diagnoses have been cited as one of the major reasons that water control treatments have been ineffective. Proper diagnostic techniques significantly enhance success of traditional treatments, both technically and commercially. The methods of diagnosing problems are:

MRI (Magnetic Resonance Imaging) Method:

The usage of a diagnostic tool is immensely important, to apply the methodologies of preventive conformance on diagnoses the source of the water problems. The MRI is a powerful logging tools for providing conformance information also known as Production Logging Tool (PLT). MRI plays a major role in designing proactive/preventive conformance because it has the capability to identify volumes of free fluids (water and hydrocarbon), the type of formation fluids, and it is also capable to identify water – free zones. The proactive conformance of MRI tool discussed by

Soliman[7] concentrated on preventing or delaying water production associated with production from oil zones.

Water Control Diagnostic Plots Method

Conventionally, water cut vs. time linear plots were used to show the progress and severity of the excessive water production problems[8]**.** Nevertheless, it is an inadequate technique to confirm or identify what type of source caused the excess of water production. **.** The correlation between water cut or fractional water flow and average reservoir water saturation for two-phase flow is also well known [9].

Diagnostic plots Derivative Method

Majid and others[10] discussed the limitations of Production Logging Tool (PLT) and focused on diagnosing excessive water production problems using water-oil-ratio (WOR) plots, which are commonly used for screening and selecting water shut-off candidates. A 3-D simulation model was used to investigate the effect of water areal coning and channeling through fractures on WOR and WOR derivative trends in vertical and horizontal wells. This technique used to determine excessive water and gas production mechanisms as seen in petroleum production wells, has been developed and verified by Chan, K. S [11], which can be considered as the most appropriate methodology for identifying the source of the water production problems. The application of this technique is a prove that log-log plots of WOR (Water/Oil Ratio) vs. time or GOR (Gas/Oil Ratio) vs. time show different characteristics response trends for different excess water production mechanisms, and moreover confirmation that WOR and GOR derivatives respect to time are founded to be capable of differentiating the response of the well whether the well is experiencing water and gas coning. In water channeling, the slope of WOR and WOR derivatives are positive constants, while water conning, shows a changing negative slope. Therefore the diagnostic plot till now is considered as a unique technique as an easy, fast, and inexpensive method to identify excessive water and gas production mechanisms.

Application of the Diagnostic plots Derivative Method:

Sudanese oil wells as case study are in Toma South field which is located, in the Muglad Basin Sudan[12]. The trap is a structural closure located on a tilted up-thrown side of a normal fault block. The trapping mechanism is a combination of fault and dip closure. Most faults in this structure approximately trend NW. One exception is a small normal fault that is oriented almost perpendicular to the major fault that divides the field into two parts. The main reservoir is the Early Cretaceous Bentiu sand [12]. The Aradeiba main sand (Late Cretaceous) is a secondary oil accumulation. Both are layered sand reservoirs with continuous barriers between these layers over a large area in the field [12]. The drive mechanism is water drive reservoir, and most of the reservoirs in this area are producing with a high water cut due a limited oil pools. Production started in 1999, and as of 2005 cumulative production was 112 million stock tank barrels (MMSTB). Rapid increase in water cut was experienced in this field, which affected oil production. Well No. 1 is 28% WC and Well No. 2 is 57% WC.

Diagnostic plots derivative technique which was explained by Chan, K. S[11], showed that the log-log plot of production data ,WOR and the WOR derivative respect to time provide more insight and information of well performance evaluation on identification of the mechanism that causes the excess water production. It can be applied either for the entire well life or any chosen period, such as the water flooded period. Concerning the application of this method for our case study**,** table 1 provides an example data for Well No.1 Sudanese oil well production data (suffering of excess water) and table 2 provides a simplified computation WOR derivative for this data by using Microsoft Excel format.

Table 1. sample production data for well No.1 (oil well suffering of excess water)

No.	***Time***	***Oil***	***Gas***	***Water***	***No.***	***Time***	***Oil***	***Gas***	***Water***
Unit	***Days***	***bbl/d***	***Mcf***	***bbl/d***	***Unit***	***Days***	***bbl/d***	***Mcf***	***bbl/d***
1	*15.35*	*54869.43*	*0*	*1891.62*	*40*	*27.86*	*9535.71*	*0*	*9951*
2	*30.52*	*82936.49*	*0*	*83.02*	*41*	*30.84*	*10098.62*	*0*	*10604.33*
3	*29.75*	*85738.8*	*0*	*85.82*	*42*	*29.44*	*7680.37*	*0*	*7869.9*
4	*28.81*	*84864.57*	*0*	*84.95*	*43*	*30.79*	*8727.41*	*0*	*9979*
5	*30.94*	*88642.93*	*0*	*88.73*	*44*	*28.33*	*5254.7*	*0*	*7082*
6	*21.77*	*95951.65*	*0*	*240.48*	*45*	*28.48*	*7599.14*	*0*	*10667.61*
7	*30.73*	*111946.6*	*0*	*2284.62*	*46*	*7.46*	*1920.2*	*0*	*2827.6*
8	*26.27*	*76683.82*	*0*	*2209*	*47*	*28.74*	*18985.9*	*0*	*36273.79*
9	*30.38*	*96818.65*	*0*	*5095.72*	*48*	*30.57*	*16449.6*	*0*	*31650.9*
10	*30.48*	*110436.8*	*0*	*15243.08*	*49*	*24.87*	*19445.6*	*0*	*37054.08*
11	*29.58*	*80518.33*	*0*	*9273.45*	*50*	*30.92*	*21152.81*	*0*	*38556.17*
12	*30.4*	*50665.42*	*0*	*9514.3*	*51*	*30.98*	*16309.77*	*0*	*26474.97*
13	*28.48*	*42289.63*	*0*	*16445.97*	*52*	*28.82*	*13224.44*	*0*	*18658.29*
14	*30.83*	*41054.28*	*0*	*16736.99*	*53*	*30.77*	*13525.05*	*0*	*19160.26*
15	*30.88*	*38198.6*	*0*	*16370.83*	*54*	*29.17*	*13991.25*	*0*	*20002.75*
16	*27.96*	*33978.09*	*0*	*14562.04*	*55*	*30.83*	*16529.16*	*0*	*22500.25*
17	*30.71*	*37251.47*	*0*	*15964.91*	*56*	*29.74*	*15548.68*	*0*	*19620.41*
18	*29.79*	*36380.59*	*0*	*20464.08*	*57*	*30.88*	*14900*	*0*	*19689.52*
19	*29.9*	*36558.53*	*0*	*20564.18*	*58*	*31*	*11612.43*	*0*	*17234.96*
20	*29.73*	*24016.69*	*0*	*13057.2*	*59*	*29.98*	*13595.54*	*0*	*21169.71*
21	*26.4*	*32932.14*	*0*	*17765.31*	*60*	*30.6*	*9710.971*	*0*	*14494.1*

Table 2. simplified computation WOR derivative for well No.1 data

WOR	*dΔt*	*ΔWOR*	*dΔWOR*	*Derivative*	*WOR*	*dΔt*	*ΔWOR*	*dΔWOR*	*Derivative*
0.034475	*0*				*0.83975*	*29.58*	*0.838748663*	*0.019185654*	*0.594372587*
0.001001	*30.52*	*0*	*0*	*0*	*0.858935*	*30.67*	*0.857934316*	*0.052271448*	*1.614091867*
0.001001	*29.75*	*0*	*0*	*0*	*0.911207*	*30.75*	*0.910205764*	*0.015472035*	*0.491990584*
0.001001	*28.81*	*0*	*0*	*0*	*0.895735*	*29.79*	*0.894733729*	*0.104265264*	*3.526608921*
0.001001	*30.94*	*0*	*0.001505255*	*0*	*1*	*30.48*	*0.998998993*	*0*	*0*
0.002506	*21.77*	*0.001505255*	*0.017901859*	*0.129219023*	*1*	*29.77*	*0.998998993*	*0.049160737*	*1.76339579*
0.020408	*30.73*	*0.019407114*	*0.008398477*	*0.051344675*	*0.950839*	*30.54*	*0.949838256*	*0.196038852*	*7.050658623*
0.028807	*26.27*	*0.027805591*	*0.023824997*	*0.194209549*	*1.146878*	*30.73*	*1.145877108*	*0.103327084*	*3.796572643*
0.052632	*30.38*	*0.051630588*	*0.085393811*	*0.687310552*	*1.043551*	*27.86*	*1.042550024*	*0.006526108*	*0.271018555*
0.138025	*30.48*	*0.137024399*	*0.022853494*	*0.206191301*	*1.050077*	*30.84*	*1.049076132*	*0.025399943*	*0.978293124*
0.115172	*29.58*	*0.114170905*	*0.072614946*	*0.747703182*	*1.024677*	*29.44*	*1.02367619*	*0.118731902*	*4.909225371*
0.187787	*30.4*	*0.18678585*	*0.201102097*	*2.215959885*	*1.143409*	*30.79*	*1.142408092*	*0.204336729*	*8.282638998*
0.388889	*28.48*	*0.387887948*	*0.018790586*	*0.239804295*	*1.347746*	*28.33*	*1.346744821*	*0.056045917*	*2.525093115*
0.40768	*30.83*	*0.406678533*	*0.020891926*	*0.267190313*	*1.403792*	*28.48*	*1.402790738*	*0.068763197*	*3.150503711*
0.428571	*30.88*	*0.427570459*	*4.64537E-09*	*6.39596E-08*	*1.472555*	*7.46*	*1.471553935*	*0.43800974*	*77.052137*
0.428571	*27.96*	*0.427570464*	*1.95441E-07*	*3.1674E-06*	*1.910565*	*28.74*	*1.909563675*	*0.013548974*	*0.632219455*
0.428571	*30.71*	*0.427570268*	*0.133928673*	*2.110063474*	*1.924114*	*30.57*	*1.923112649*	*0.018588499*	*0.834038035*
0.5625	*29.79*	*0.561498942*	*2.39593E-07*	*4.13099E-06*	*1.905525*	*24.87*	*1.90452415*	*0.082780567*	*4.648293595*
0.5625	*29.9*	*0.561499181*	*0.018828267*	*0.342265141*	*1.822745*	*30.92*	*1.821743584*	*0.199486261*	*9.209271636*

Results and Discussion:

Generally the diagnostic plot figures show the WOR increasing with time. The rate of increase differs for a different problem mechanism. The degree of sharp or gradual rate of increase presents a striking difference between coning and channeling. The other mechanisms can be identified through derivative response.

Diagnostic plot of well NO.1 (Case Study)

refers to the Case Study of Well NO.1 figure (1) compared with figure (2) ,showed that until 100 days left the WOR is very low indicating that most percentage of fluids produced are oil. After 200 days the rate of increase of the WOR is relatively slow and gradually approached a constant value at the end of this period. During this time, since WOR derivative vs time showed a negative slope water cone was formed and grew vertically upward from bottom water, covered most of the perforation interval and also expanded in a radial direction. The oil saturation within the cone gradually decreased to the residual oil saturation level, which indicated bottom water drive coning.

Before the beginning of formed water coning at the point of 150 days, there was a sharp increase in WOR at 122 days that may indicate a high rate of pump lifting after a favorable high oil cut period from 91 to 122 days (low WOR).

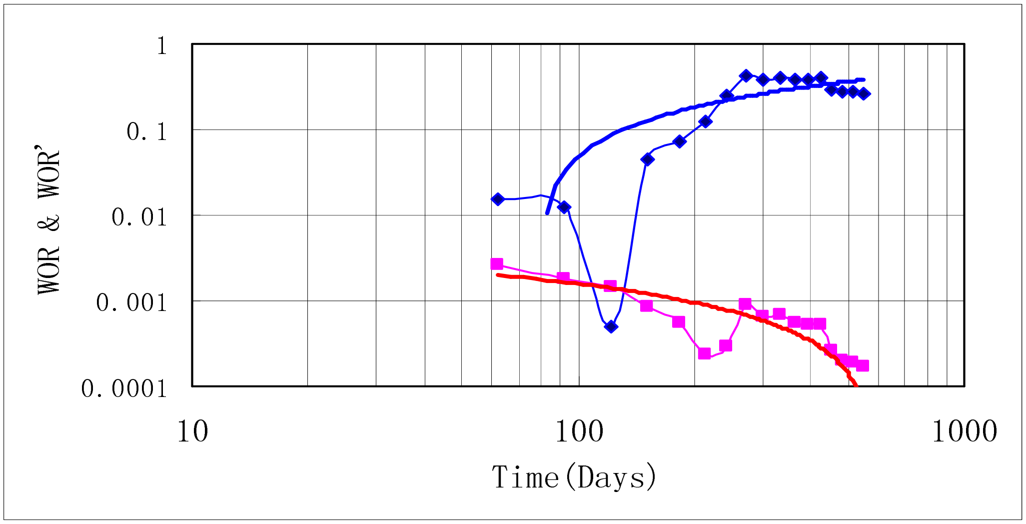

Figure 1: WOR and WOR' derivatives Plot For Well No. 1

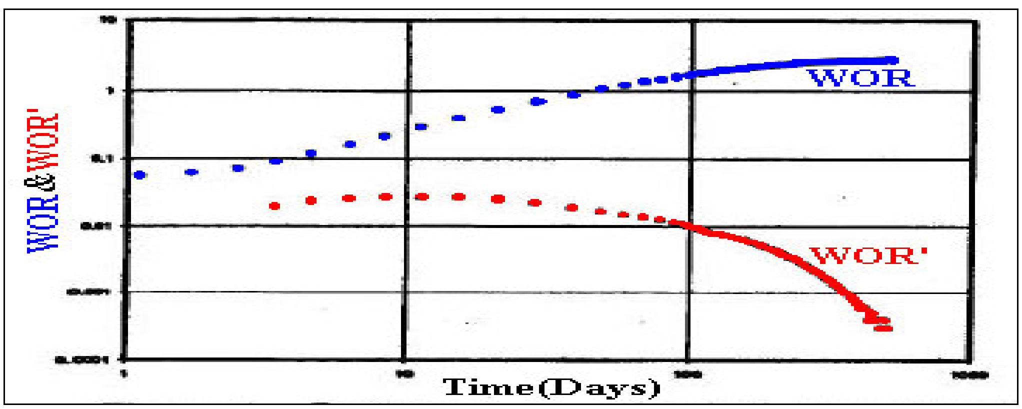

Figure 2: Chan, K. S Plot Bottom water coning Situation (WOR' negative slope), WOR and WOR' derivatives (After Chan, K.S. [11])

Diagnostic plot of well NO.2 (Case Study) As shown in figure 3 (A and B) for well NO.2 a water coning response in a good sandstone example area was at around 700 to1500 days, at this period of time since WOR derivative started to decline and showed negative slope water coning was visible. Construction of a pseudo steady-state cone was completed after about 1500 days and the slope of WOR' vs time showed a linear positive slope indicating initiation of water channeling. The same diagnosis feature can be conducted by Chan, K.S Plot figure 4, where a water coning started after 1000 days and a pseudo steady-state cone was completed at about 2000 days. Table 1; show the data of well No1, Table 2 shows the explanation of a simple way on calculation procedures of WOR and WOR Derivative.

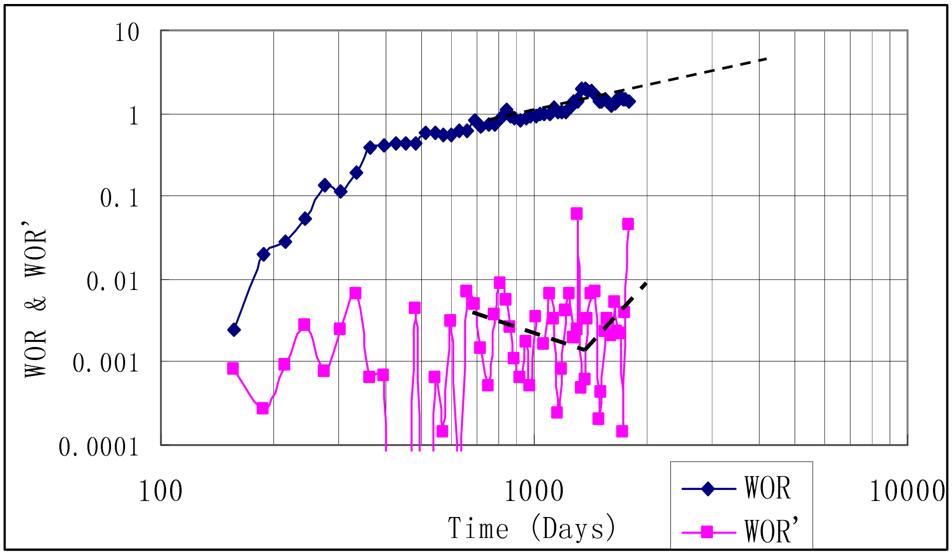

Figure 3 A: WOR and WOR' derivatives Plot for Well No. 2

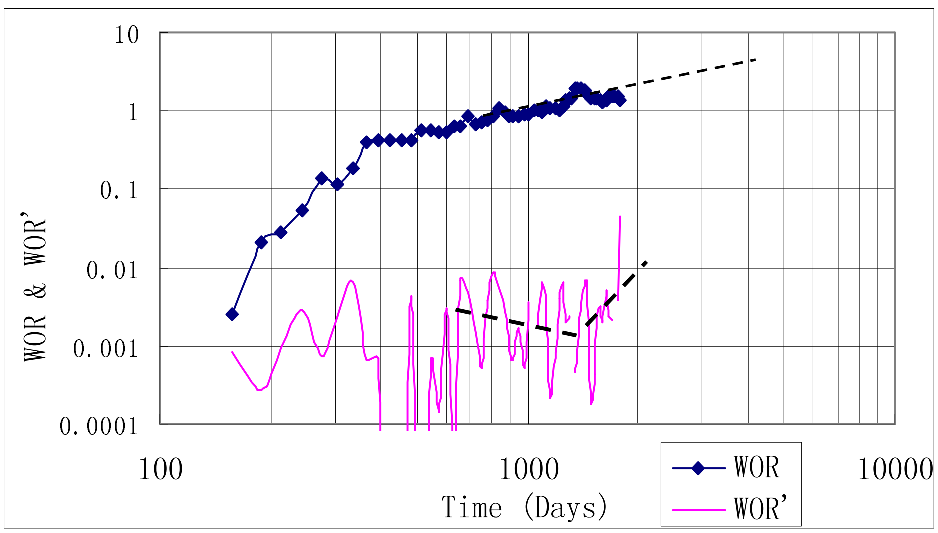

Figure 3- B: Derivative Smoothing Data Plot Well No. 2

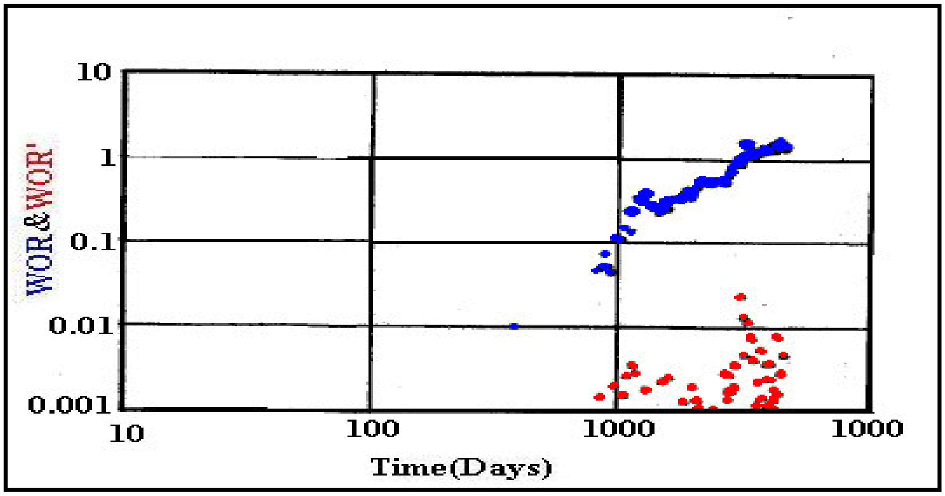

Figure 4: Chan, K. S Plot bottom water coning at sandstone area (After Chan, K. S. [11])

CONLUSIONS:

When an oil field is facing excess- water production problems, the simplest problems should be solved immediately then the diagnosis of water production problems should be started with any available information at that time.

A high production rate is extremely important factor of appearance of water coning and fast water fingering due to unfavorable mobility ratio, which lowers the recovery efficiency of oil by water displacement, Care should be taken, when an artificial lifting pump is set at a high rate, especially after well shutoff period.

The optimum pumping flow rate should be technically designed for each well below the critical value of forming water coning, in order to prevent early stage water breakthrough, and thus enable maximization of the oil reserves.

A preventive/proactive conformance process by using logging tools can delay or prevent excess water production. It can provide a higher hydrocarbon production without adventuring of early water breakthrough problems.

The water coning and channeling can be clearly identified using of WOR derivative.

Moreover the change in slope of WOR and WOR' and the value of WOR' are good indicators for differentiation of normal displacement and production behavior.

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