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New Analytical Method for Improving Water Allocation Management in Water Flood Projects

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Abstract

Water production is one of the big challenges of oil and gas recovery. This excessive water production is a significant operational, economic and environmental problem. One of the main causes of water production is an improper water injection plan. Thus, the waterflood projects should be managed in a manner to delay the water breakthrough in producers as much as possible, and as a result improves sweep efficiency and increases the oil recovery. One of the proposed new approaches to an efficient waterflood project is the Water Allocation Management (WAM). Water Allocation Management aims to inject the water in a manner that increases the total oil recovery for a given volume of water. The good injectors are thus those which support the good producers. Inter-Well Connectivity of producers and injectors is an important parameter which affects the efficiency of allocation management in waterflood projects. Inter-well connectivity determines how effectively injection and production wells are connected to each other. One of the methods recently employed by petroleum engineers to measure this parameter is the Capacitance-Resistance Model (CRM). CRM assumes the reservoir as a system which gets an input signal (injection rate) and responses by an output signal (production rate). By analyzing these behaviors, a series of equations are written to correlate the output and input signals. In these equations, there are two main unknown parameters. The first one is the time constants, and the second is the weight factors (well connectivity parameters). These parameters can be determined by history-matching the production/injection rates. After finding the unknown parameters, by employing the weight factors and the water cut from production wells, a new analytical algorithm is presented to calculate the allocated factor for each injection wells to improve waterflooding in order to increase the cumulative oil production and reduce the cumulative water production.

Keywords: Waterflooding, Water Allocation Management, Capacitance-Resistance Model, Inter Well Connectivity, Effective Oil Production Index.

Introduction

Behavior of fluid flow between injectors and producers and quantifying their connection are important parameters for controlling the injection plan and the success of waterflooding [1]. Using numerical reservoir simulators for this purpose seems to be time-consuming and so complex. Therefore, implementation of a model with low data requirements with reliable performance is an important goal for efficient water injection management. Variety of methods have been proposed for inter-well connectivity measurement each having specific limitations. One of the new material balance based approach recently employed by petroleum engineers is capacitance-resistance model (CRM) [2]. However, first study on inferring well pair connectivity only from injection and production data was introduced by Albertoni and Lake [3]. Then the mathematical derivation of CRM by combination of two parameters, known as a connectivity factor and response delay was modified by Yousef et al [4]. After that,semi-analytic formulations based on three different reservoir control volumes were proposed by Sayarpour et al: 1) effective volume of each producer; 2) volume between each injector/ producer pairs; 3) total filled control volume [5]. Since then, this reliable method was implemented on different field case studies [6, 7].

In this research, CRM method is conducted on a synthetic reservoir model. Production and injection history of producers and injectors of this model are used to obtain the unknown parameters of CRM equation. After that, a new analytical algorithm is derived that combines the injector-producer connectivity results from CRM with the water cut from production wells to define a new water allocation factor for injection wells. This new approach is employed to improve waterflood in a manner to increase the oil recovery and reduce water production.

Methodology

CRM, primarily assumes the reservoir as a system which gets an input signal (injection rate) and responses by an output signal (production rate). By analyzing these behaviors, a series of equations are written to correlate the output and input signals. In these equations, there are two main unknown parameters; time constants and the weight factors. These parameters are briefly described below [5]:

Weight factor (well pair connectivity): this parameter represents the fraction of injected water that flows from an injector towards a producer [4]. According to equation 1 the well pair connectivity between injector i and producer j is indicated by f_{ij} and the sum of them for one injector is normally in the range of [0 to 1] [5].

Time constant: observing the time constant demonstrates the delay, which takes for input signal (injection rate) to reach the producer and cane, as output signal (production rate). Figure 1 shows the impact of time constant.

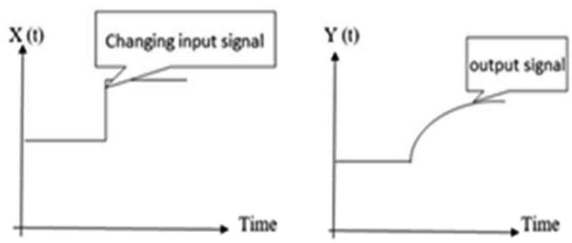

Figure 1: Effect of time constant on output signals.

Mathematical Formulation of CRM

Based on the type of drainage volume, there are three different formulations for CRM. In this study, one time constant for each producer is selected to determine CRM variables, which is called CRMP. In this model, for a pattern of *I* number of injectors and *N* number of producers, the in-situ volumetric balance over the pore volume of a producer is applied. Based on the continuity equation, "equation 1" demonstrates the production rate of each producer [5]:

$$q_p(t) = \sum_{i=1}^{N_i} f_{ip} I_i(t) - \tau_p \frac{dq_p(t)}{dt} \quad (1)$$

Analytical solution, which is discretized over the time, can be presented as "equation 2":

$$q_p(t_k) = q_p(t_{k-1}) e^{-\frac{t_k - t_{k-1}}{\tau_p}} + (1 - e^{-\frac{t_k - t_{k-1}}{\tau_p}})(\sum_{i=1}^{N} f_{ip} I_i^{(k)} - J_p \tau_p \frac{\Delta p_{wf,p}^{(k)}}{\Delta t_k}) \quad (2)$$

Two CRM main parameters, f_{ij} and τ_j, can be obtained by using the reservoir production and injection history. The objective function is to minimize error between the calculated production rate using CRM and the observed production rate.

New Analytical Technique to Define Improved Water Injection Allocation Factor

In order to improve waterflooding performance, the production well with higher rate and lower water cut should be well supported by its connected injectors. For this reason, the injector which has a better connection with this producershould have higher injection rate. The production well with low oil rate and high water cut is prone to or likely to earlier breakthrough. Thus, lower injection rate should be allocated for injectors associated to this producer [8].

The improved allocation of water between injectors can be calculated using the following new analytical procedure:

1. Inferring the weight factors of injector-producer by employing CRM.

2. Determining the Water Production Index (WPI) of pair injector/producer. This parameter is defined as "equation 3":

$$WPI_{ip} = f_{ip} \times WC_p \times q_p \quad (3)$$

where WPI_{ip} is Water Production index of producer p that is connected to injector *i*, f_{ij} is weighting factor of producer *p* in connection with injector *i*, WC_p is the water cut of producer *p*, and q_j is the liquid production rate of producer *p*.

3. Determining the Oil Production Index (*OPI*) of pair injector/producer. This new parameter is defined as "equation 4":

$$OPI_{ip} = f_{ip} \times (1 - WC_p) \times q_p \quad (4)$$

where OPI_{ip} is Oil Production index of producer *p* that is connected to injector i.

4. By Taking *OPI* and *WPI* into account, the Effective Oil Production Index (EOPI) of pair injector/producer can be defined as "equation 5":

$$EOPI_{ip} = OPI_{ip} - WPI_{ip} \quad (5)$$

where $EOPI_{ip}$ is Effective Oil Production Index of producer *p* that is connected to injector *i*.

5. The improved allocation factor of each injector is calculated as "equation 6":

$$IWIAF_i = \frac{EOPI_i}{EOPI_T} \quad (6)$$

where $IWIAF_i$ is the improved water allocation factor of producer *i*. $EOPI_i$ is the Effective Oil Production Index of injector *i*. this parameter is defined as "equation 7" and $EOPI_T$ is the sum of $EOPI_i$ for all injectors:

$$EOPI_i = \sum_{p=1}^{p=N_p} EOPI_{ip} \tag{7}$$

Results and Discussion

A reservoir containing 4 injectors and 3 producers is employed to evaluate and examine the proposed new method for water allocation management.

A 10-year history of injection and production downhole rates are used to determine the interwell connectivity using *CRMP*. According to *CRMP* results, time constants and weight factors of the wells are determined. Table 1 presents these parameters, and the water cut of producers are shown in "table 2".

Table 1: CRM parameters.

Parameter	P_1	P_2	P_3
τ_p	10.21	75.32	150.13
f_{1p}	0.51	0.1	0.37
f_{2p}	0.33	0.15	0.43
f_{3p}	0.15	0.3	0.47
f_{4p}	0.16	0.6	0.22

Table 2: Water cut of each producer.

Parameter	P_1	P_2	P_3
Water cut	0.44	0.56	0.26

IWIAF was calculated and used to manage the injection rate of the injectors for the next 20 years of the production. Results of the base case scenario (allocating 25 percent of total injected water to each injector) is compared with improved water allocation management (WAM) scenario. Figure 2 and figure 3 show the cumulative oil production and total water cut in both scenario respectively.

Conclusions

In this study, by employing CRM and a new index definition, known as Effective Oil Production Index, a new algorithm is presented for water allocation management. With the aid of this algorithm, the allocated injection rates for each of the injectors are determined. Based on the study outcomes or results, the following conclusions can be drawn:

1. For the fixed amount of injection fluid, the new algorithm improves water allocation to put the water front in the right direction resulting in better injection scenarios and sweep efficiency.

2. The injection scenario based on new technique, significantly improves the recovery factor, which in turn considerably raises the oil production and causes a significant drop in water cut.

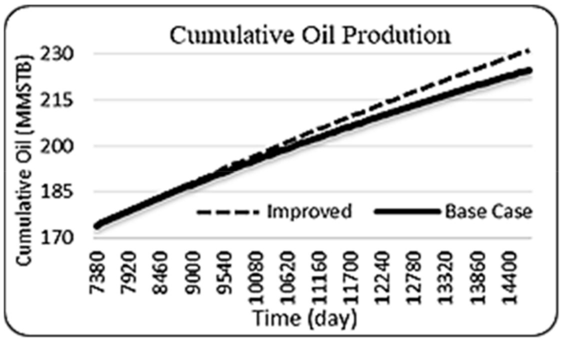

Figure 2: Plot of oil cumulative oil produced versus date for both injection scenarios.

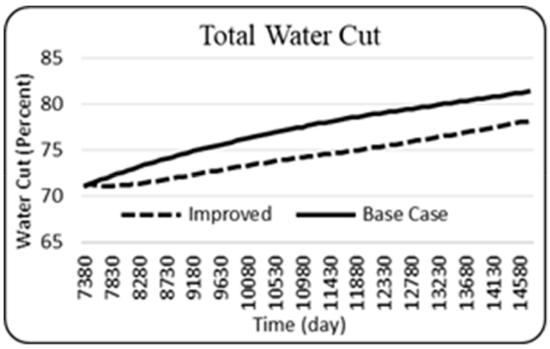

Figure 3: Plot of total water cut versus time for both injection scenarios.

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