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DEVELOPMENT OF A DUAL-POROSITY MODEL FOR «BACH HO» FRACTURED BASEMENT RESERVOIR

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This paper describes an approach for development of dual-porosity model of fractured reservoirs by integrating the parameters of relatively well calibrated single-porosity model and other available data. The parameters of dual-porosity model such as porosity and permeability are obtained from splitting procedures of single-porosity model parameters which are considered as the total effective parameters of fractured porous medium. Other parameters of dual-porosity model may be determined by geology, petrophysics, core analysis or theoretical data. In this paper, the application of this approach to «Bach Ho» (White Tiger) fractured basement reservoir (FBR) in Vietnam are presented. Successful history matching results obtained in a long period of time for the reservoir show the advantage of the approach.

Keywords: «Bach Ho», fractured reservoir, matrix, dual-porosity, effective parameters, ECLIPSE.
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1. Introduction

As the number of the world's hydrocarbon fractured reservoir assets is growing, it has become increasingly important to develop new approaches for fractured reservoir modeling and simulation. Reservoir simulation could answer several crucial issues such as the selection of the «best» or «optimum» recovery process (technical and economical) for a given reservoir, the calculation of production profiles and of expenses (operating costs and capital expenditure), and the risk evaluation. Numerical simulations have become a reservoir management tool at all stages of the reservoir life. This is particularly true in the case of fractured reservoirs [1,2].

«Bach Ho» is one of the largest oil fields on the Vietnam's continental shelf located in Cuu Long Basin. According to exploration and production data from the field, the main oil reservoir of «Bach Ho» is a fractured basement containing macro, micro fracture systems and vugs with a high degree of heterogeneity. The issue of data characterization for elaborating an accurate simulation model of the reservoir is particularly essential for reservoir development decision. Location and depth maps of «Bach Ho» top FBR are shown in figure 1 [3,4].

There were many simulation models for the «Bach Ho» FBR, but like the majority of the reservoir simulation models for fractured granitoid basement reservoirs in Vietnam, although carefully built and well history matched, after a period of use still gave forecast results largely different from reality. One of the reasons is that most of current models use conventional single-porosity models, while the fractured reservoir itself would behave like dual-porosity medium. The «Bach Ho» oil fractured granitoid basement is a reservoir with negligible storage capacity for the granitoid rock but contains many fractures of different scales so that it could be considered as a dual-porosity medium in which the system of micro fracture plays a role for oil storage and the macro fracture system serves mainly for oil conductive path (fig.2, [5]). There are major differences between hydrodynamic mechanism

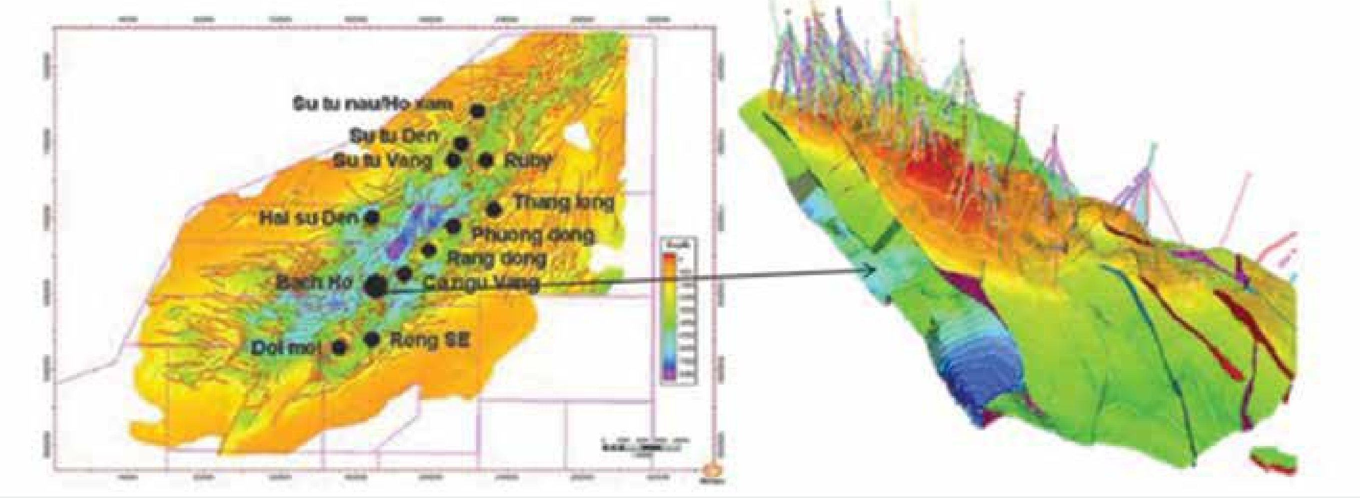
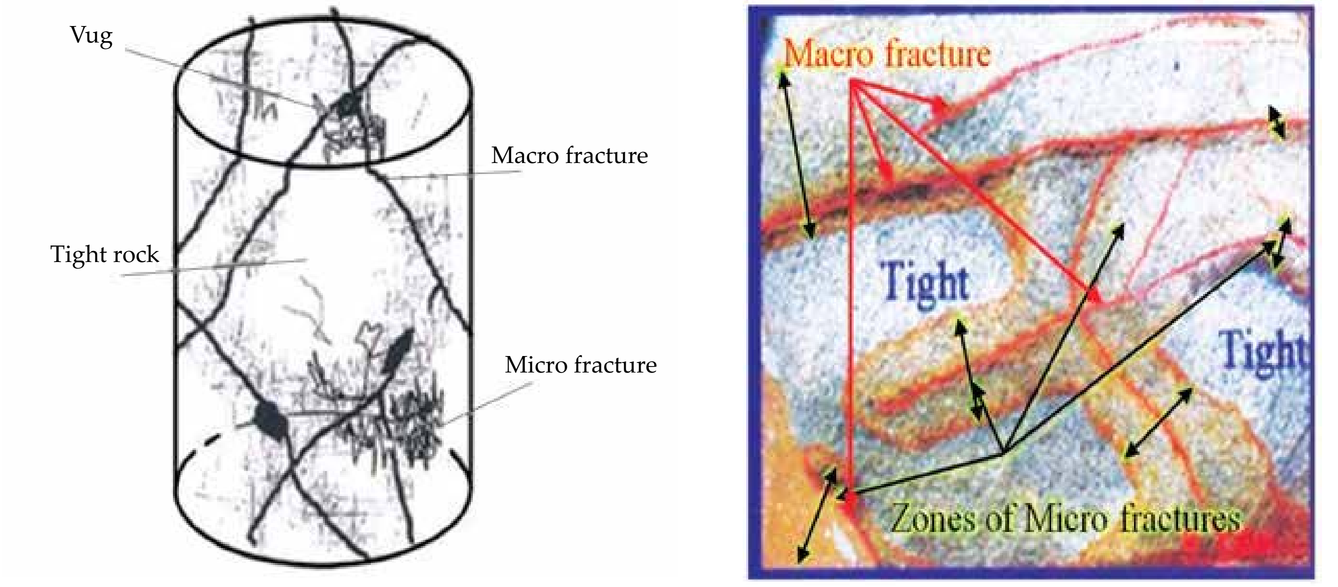


Fig.1. Location and depth maps of «Bach Ho» top FBR



a) Pore characteristics **b) A fractured granite outcrop**

Fig.2. Pore characteristics of «Bach Ho» FBR

of single-porosity model and dual-porosity model, therefore single-porosity models though improved and updated constantly could not provide good long-term forecast for the reservoir behaving, in practice, as a dual-porosity medium. Especially in water injection/influx stage, many special effects of dual-porosity medium could not be neglected. A good review of the recovery mechanisms in fractured reservoirs can be found in (Firoozabadi, 2000) [1].

This paper presents an approach for development of dual-porosity model for Bach Ho FBR based on a combination of available field data and the parameters of a single-porosity model that has been applied successfully for the reservoir. In this approach, the parameters of the single-porosity model are considered as total effective parameters for fracture systems of all scales (macro, micro fractures and vugs). The parameters such as porosity and permeability are obtained from splitting procedures of total effective parameters. Other parameters of dual-porosity model may be determined by geology, petrophysics, core analysis or theoretical data.

2. Data analysis for dual-porosity model

The dual-porosity approach was first proposed by Barenblatt and Zheltov (1960) [6] in order to simulate the flow behavior in fractured porous media. This concept has been applied by Warren and Root (1963) [7] to model the transient well test responses of fractured reservoirs. The essence of the dual-porosity model is to consider fractured reservoir as a system of two separate porous continua but overlapping and interacting. The first medium that contains totally high storage for oil but weak hydraulic conductivity (micro fractures, porous rocks, ...) is identified as the matrix system, the second medium that contains less storage but high hydraulic conductivity (macro fracture system, conductive faults ...) is identified *as fracture system*. Fluid motion in these two media obey the flow equations of independent porous medium and the mass transfer between matrix block and fracture system is accounted for by «source function» and can be modeled [8]. Recently, continuous progresses have been made for fractured reservoir modeling, especially in the modeling of matrix-fracture transfers and fracture characterization. The dual-porosity model was adopted as the underlying model of all industrial fractured reservoir simulators and are widely used in the petroleum industry for field-scale simulations of recovery processes in fractured reservoirs [2].

For most fractured reservoirs, hydrocarbons are stored in its porous matrix rock and the application of dual-porosity model is suitable, and maybe, not very complicated. In contrast, Bach Ho FBR has tight matrix rock, so application of dual-porosity could not be straightforward. According to Ngo Thuong San [5] and Hoang Hong Linh [9], in «Bach Ho» FBR oil is stored in micro vugs/cavities and micro fractures (with aperture size $b \le 60$ μm) that act as a matrix system, while macro fractures (with aperture size $b > 60$ μm), large vugs/cavities and conductive faults are significant for fluid conduction that act as a fracture system in dual-porosity model.

The parameters of dual-porosity model can be obtained by different techniques of fracture characterization and geologic modeling. But the workflow is very complicated, time consuming and expensive [10]. Because the single-porosity model for «Bach Ho» elaborated by Viesovpetro [3] is based on the parameters from core analysis, well testing and production-log data and is quite well calibrated, so it's parameters such as porosity, permeability can be considered as total effective parameters representing the entire system. Therefore, the parameters of dual-porosity model can be determined based on splitting procedures that are presented below.

2.1. Porosity splitting procedure

It can be assumed that total effective porosity used in the single-porosity model is the sum of matrix porosity and fracture system porosity [11]:

$$\phi_T = \phi_m + \phi_f \tag{1}$$

where: ϕ_T is the total effective porosity;
ϕ_m is the porosity of matrix;
ϕ_f is fracture system porosity.

In general, the fracture system porosity is very small in comparison with the porosity of matrix.

From the equation (1), porosities of two media in dual-porosity model can be determined based on porosity percentage ratio of macro/micro fractures.

Based on analysis of geophysical borehole data of 163 wells into Bach Ho FBR, the average ratio of fracture porosity macro/micro in 12 regions (porosity regions of single-porosity model of Bach Ho) can be is calculated and given in table 1.

2.2. Permeability splitting procedure

In general, total effective permeability or equivalent of dual-porosity model can be determined by different conceptual models depending on geometrical structure of fracture system. An excellent review on these conceptual models may be found in [8]. In this work, a very simple model based on volumetric averaging is used [11].

Table 1

Average ratio of fracture porosity macro/micro in 12 regions.

Region	Minimum Porosity	Maximum Porosity	Porosity Ratio macro/micro
1	0.00%	0.39%	4.55%
2	0.39%	0.50%	1.79%
3	0.50%	0.59%	1.04%
4	0.59%	0.68%	1.61%
5	0.68%	0.77%	2.05%
6	0.77%	0.87%	2.11%
7	0.87%	0.97%	2.08%
8	0.97%	1.09%	2.97%
9	1.09%	1.24%	2.74%
10	1.24%	1.44%	3.43%
11	1.44%	1.77%	3.64%
12	1.77%	5.04%	6.90%

The splitting procedure of permeability for matrix and fracture system adheres to two steps:

Total effective permeability is equal to the sum of permeabilities of two media:

$$K_T = K_m + K_f \qquad (2)$$

where: K_T is the total effective permeability;
K_m is the permeability of the matrix;
K_f is the permeability of the fracture system.

Matrix permeability has a close relationship with the matrix porosity:

From the results of research on core permeability, SSI [12] proposed a relationship between permeability (K_m, mD) and porosity (ϕm, %) of matrix of Bach Ho FBR as follows:

$$K_m = 10^{(0.5\,\phi_m - 3.0)} \qquad (3)$$

Hence, after calculation of ϕ_m from porosity splitting step, K_m is determined from (3) and then K_f can be obtained from equation (2).

2.3. Relative permeability curves

Relative permeability curves of the two systems of dual-porosity model can be obtained from effective relative permeability curves of single-porosity model based on a model developed by Shaohua Gu et al., 2014 [13].

Typically relative permeability curves of fracture system has the form of the letter X (X-style) and is assumed known, then relative permeability matrix can be determined by the equations:

$$k_{rwm} = (\alpha + 1) k_{rwT} - \alpha k_{rwf} \qquad (4)$$

$$k_{rom} = (\alpha + 1) k_{roT} - \alpha k_{rof} \qquad (5)$$

where: k_{rwm} is the water relative permeability in matrix;
k_{rwf} is the water relative permeability in fracture;
k_{rom} is the oil relative permeability in matrix;
k_{rof} is the water relative permeability in fracture;
k_{rwT} is the water effective relative permeability of the two media;
k_{roT} is oil effective relative permeability.

The factor α is a function of space coordinates and is calculated by:

$$\alpha = (K_{ff} / K_m)(\varphi_f / \varphi_m) \qquad (6)$$

where: K_{ff} is the intrinsic fracture permeability;
K_m is the permeability of matrix.

2.4. Capillary pressure curves

As it is well known that the effects of capillary pressure P_c are very important in dual-porosity model. A dual-porosity simulator uses the mechanisms of fracture-matrix fluid transfer for modeling, i.e. capillary imbibition, gravity drainage, pressure equilibration viscous displacement [2]. Due to the capillary forces water can penetrate into the matrix to push oil out of the matrix. Capillary pressures are often neglected in single-porosity models, in the single-porosity model for «Bach Ho» FBR the capillary effects have not been calculated because they were taken as a constant value equal to zero (P_c = 0). This study used theoretical capillary pressure curve according Kazemi (1976) [8]. Figure 3 shows an example of a capillary curve in a region of «Bach Ho» dual-porosity model.

2.5. Fracture-matrix transfer factor

As it is mentioned above, the dual-porosity model comprises an interconnected fracture system that provides the main flow paths (they have high permeability and low storage volume), and the matrix (micro fractures or reservoir rock) acts as the main source of fluids such as hydrocarbons… (they have low permeability and high storage volume). Thus it is the matrix system that contains most of the oil, but the production of oil to the wells is through the high permeability fracture system, implying that it is the matrix-fracture interaction that mainly controls fluid flow. Production from the matrix-fracture system can be associated with various physical mechanisms including oil expansion or pressure diffusion, imbibition or saturation diffusion,

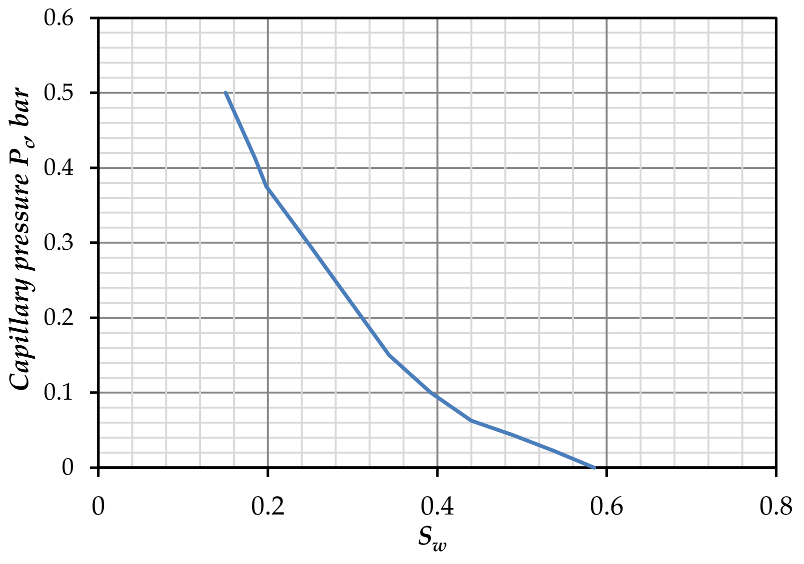


Fig.3. Capillary pressure curve in a region of «Bach Ho» dual-porosity model

gravity imbibition or drainage, mass diffusion and viscous displacement or convection (ECLIPSE 100 Technical Description, 2009 [14]). This interaction can be described using a transfer function. There are different models for matrix-fracture transfer function and most dual-porosity models require a shape factor σ depending on geometrical characteristics of the matrix block [15]. This study applied an option in ECLIPSE 100 software that uses Kazemi shape factor for rectangular geometry [8]:

$$\sigma = 4\left(\frac{1}{L_x^2}+\frac{1}{L_y^2}+\frac{1}{L_z^2}\right) \qquad (7)$$

where: L_x, L_y, L_z are dimensions of matrix block in direction x, y, z respectively.

3. Dual-porosity for «Bach Ho» reservoir

3.1. Parameters of dual-porosity model

The Bach Ho FBR is divided into 44 horizontal layers. The grid number for the directions X,Y,Z are 88x232x44, respectively. The data on permeability, porosity, as well as the parameters PVT are set for each grid cell or reservoir regions. In dual-porosity model, each grid represents two overlapping porous media, so the computation grid number is doubled.

According to research by SSI [12] and Nguyen Chu Chuyen [16], the average density of macro fractures in «Bach Ho» basement is about 3 fractures/m, and tends to decrease with depth. In this study, some different values of fracture density has been conducted in numerical simulation runs, the results showed that the average distance between the fractures of 1.2 m was reasonable. With this assumption, when applying the equation (7) for the shape factor of Kazemi, it gives $\sigma = 8$.

After using data processing method as described above, the porosity and permeability values for matrix and fracture systems have been determined for each numerical cells. The porosity varies in the range from 0 to 4.76% for the matrix and from 0 to 0.5% for the fracture system; the permeability varies in the range from 0 to 0.246 mD for the matrix and from 0 to 3437 mD for the fracture system (fig.4). The oil/water relative permeability curves in the matrix vary by regions. For the fracture system, this study assumes typical relative permeability of X-type.

Figure 5 shows the matrix relative permeability curves of 12 regions of Bach Ho FBR. It can be noticed that connate water saturation (S_{wc}) = 0.15 for all 12 regions. Oil residual saturation (S_{or}) varies from 0.6 to 0.7 for regions 1 to 12. Comparison between total effective and matrix relative permeability curves for regions 1 and 12 is presented in figures 6, 7. Maximum water relative permeability (K_{rwmax}) values vary between 0.323 (region 1) to 0.528 (zone 12). These values are smaller than those of effective relative permeability values which are in the range from 0.385 (region 1) to 0.571 (region 12).

3.2. Results and discussions

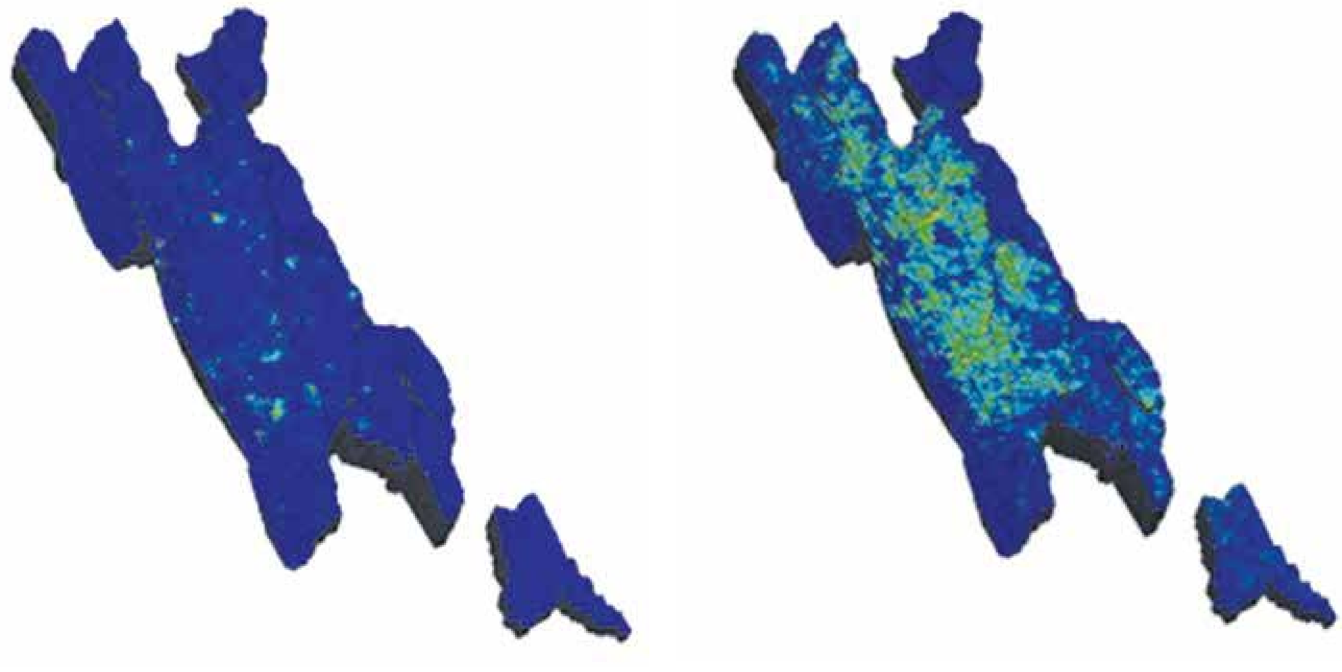
The dual-porosity model for «Bach Ho» FBR has been run for history matching for the period of 24 years from 9/1988 to 9/2012. The comparison between simulation results of single-porosity model, dual-porosity model and real recorded field data for cumulative water production, water cut and water rate are shown in figures 8, 9 and 10.

Figure 8 shows the results comparing the cumulative water production of the dual-porosity model with that of the single-porosity and the field data. It can be found that the dual-porosity model reproduces history better than the single-porosity model. Likewise, it shows better history matching for water cut and water production rate (fig.9,10), particularly evident in the final stages of the sequence data. However, similar to the single-porosity model, the results of dual-porosity model still show the large fluctuation of the water cut, and in consequence, water production rate in some certain time period. To overcome this phenomenon, the model parameters should be described more accurately on the basis of the results of experiments and fracture characterization techniques specially focusing for dual-porosity model. Therefore, the dual-porosity model for Bach Ho reservoir should be improved to obtain better results.

For bottom hole pressure, the dual-porosity model also produces better matching with measured data compared to the single-porosity model. Examples of results for wells X1 and X2 are presented in figures 11 and 12. It can be found that both models, the dual-porosity and single-porosity simulate bottom hole pressure relatively consistent with historical data for early period of exploitation. However, in later time period the single-porosity model gives bottom hole pressure much lower than measured data, while the bottom hole pressure in dual-porosity model fit quite well with the measured data all periods of exploitation.

4. Conclusions

A dual-porosity model has been developed for «Bach Ho» FBR based on the relatively well calibrated parameters of a single-porosity model and selected field data. Although many assumptions on model parameters have been made, the dual-porosity model gives the results for history matching much better than those of the single-porosity model. Hence, it can



a) Matrix permeability

b) Fracture permeability

Fig.4. Permeability used for dual-porosity model. Red is high, blue is low

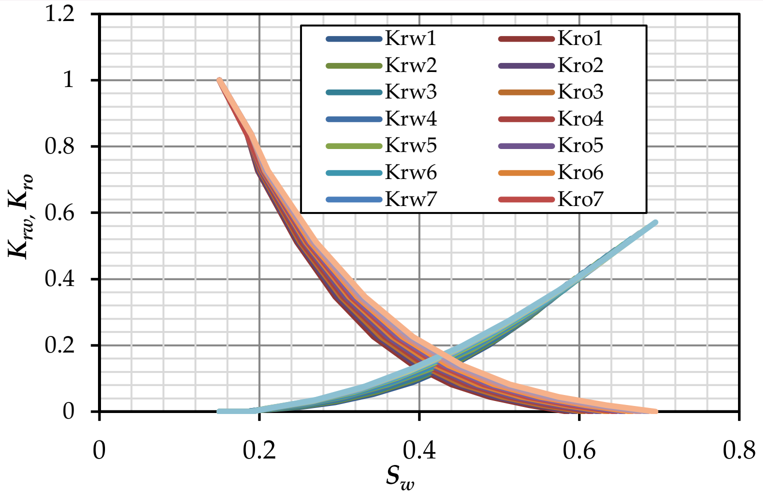


Fig.5. Relative permeability curves of matrix for 12 regions of «Bach Ho» FBR

be concluded that the method of elaborating dual-porosity model based on the effective parameters of a single-porosity model is reliable and has good scientific basis to develop simulation models suitable for fractured reservoir management and forecasting, especially in late stage of exploitation.

To improve the dual-porosity model, it is necessary to conduct additional studies for getting more accurate proportion of macro/micro fractures, studies in the relative permeability curves, capillary curves of the two systems separately, and possibly applying the advanced model calibration methods.

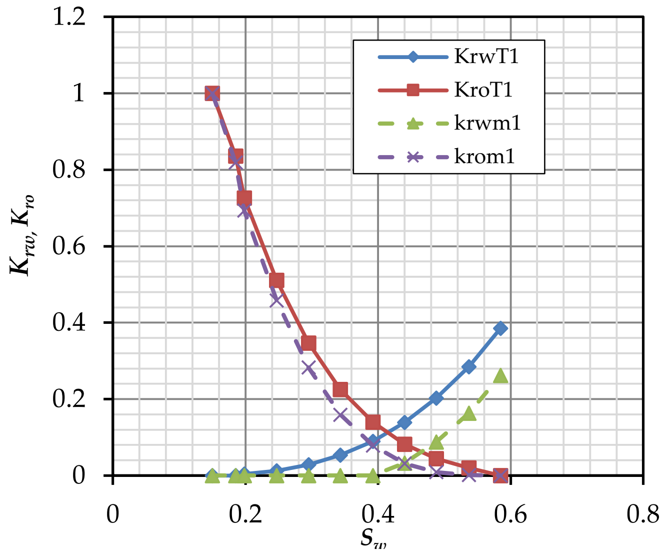


Fig.6. Comparison between total effective and matrix relative permeability curves for region 1

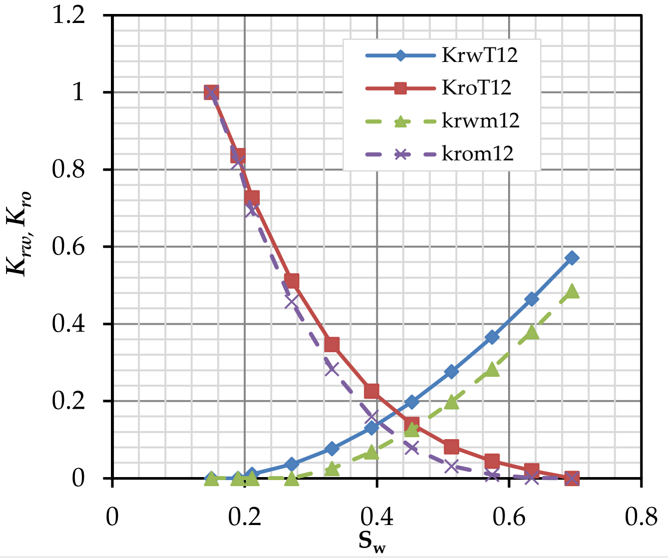


Fig.7. Comparison between total effective and matrix relative permeability curves for region 12

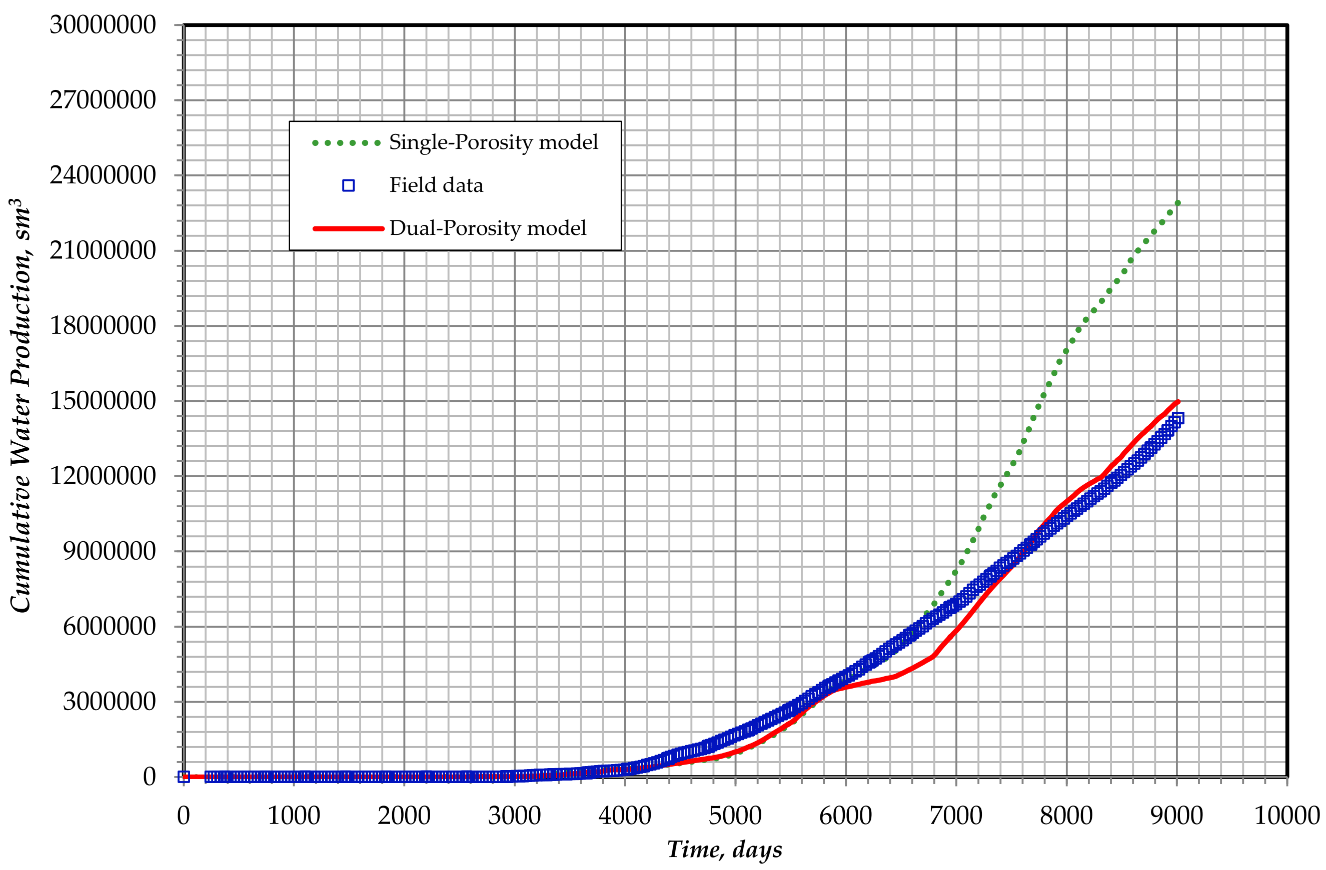


Fig.8. Comparison results for cumulative water production

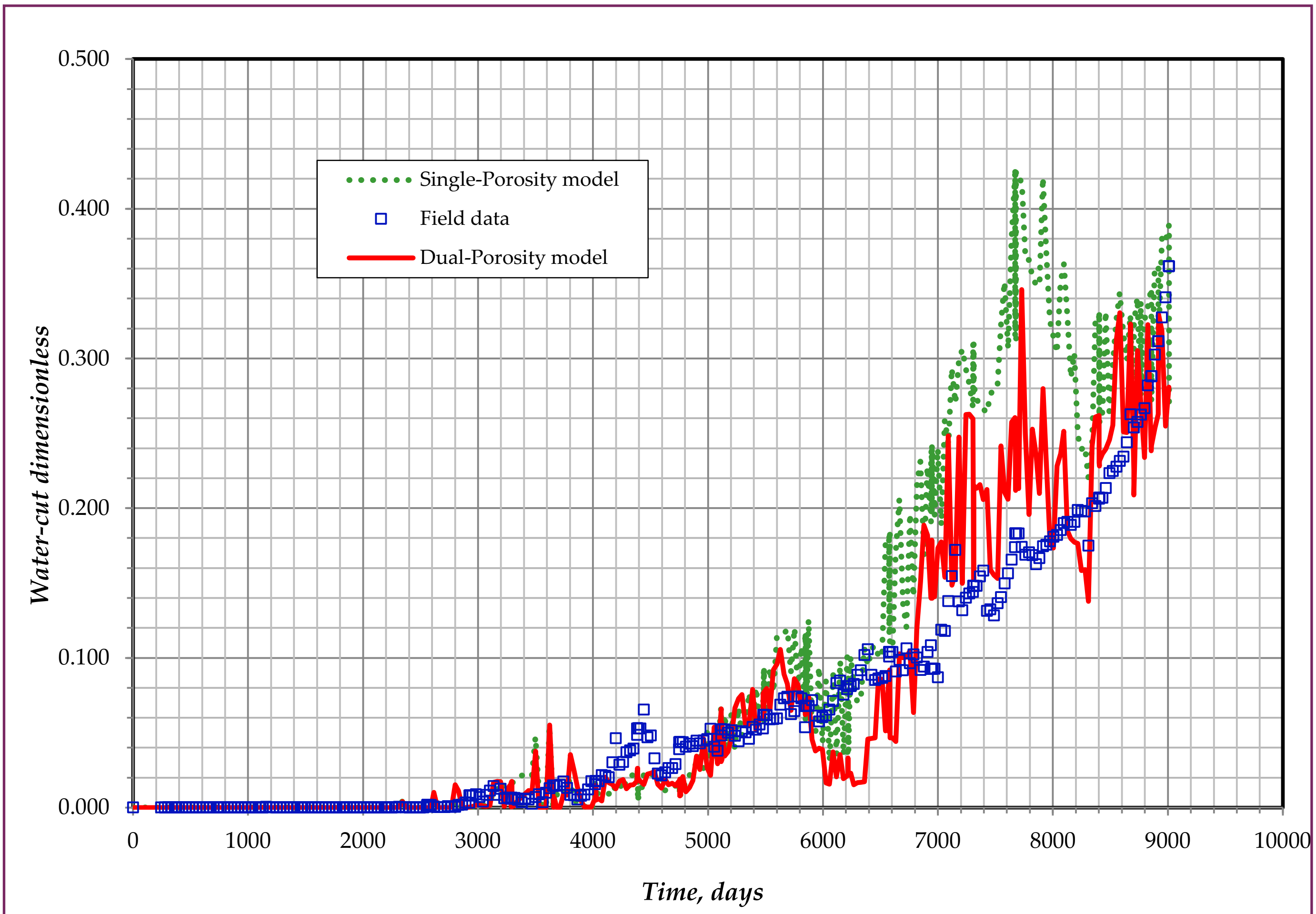


Fig.9. Comparison results for field water cut

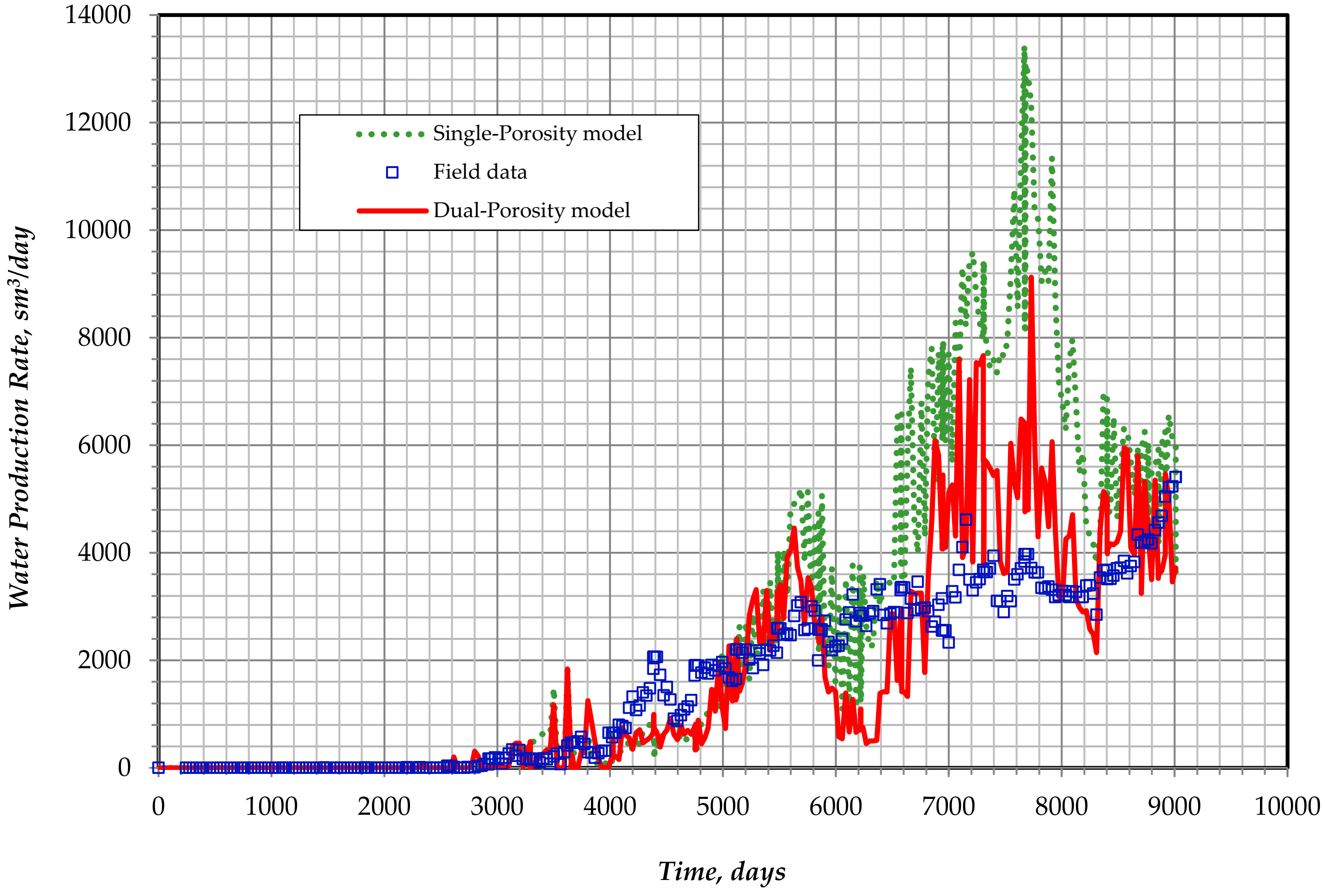


Fig.10. Comparison results for field water production rate

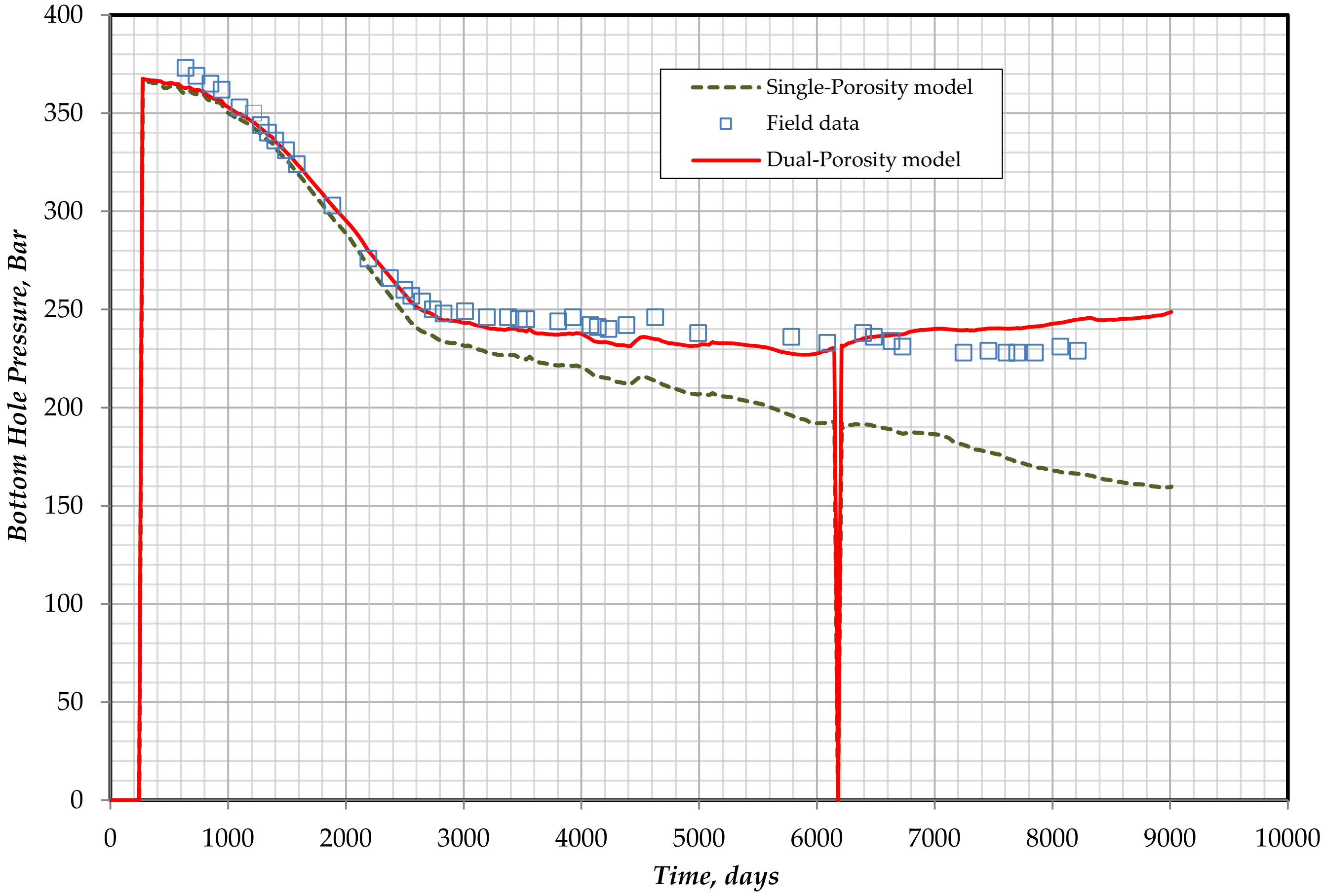


Fig.11. Comparison results for bottom hole pressure in well X1

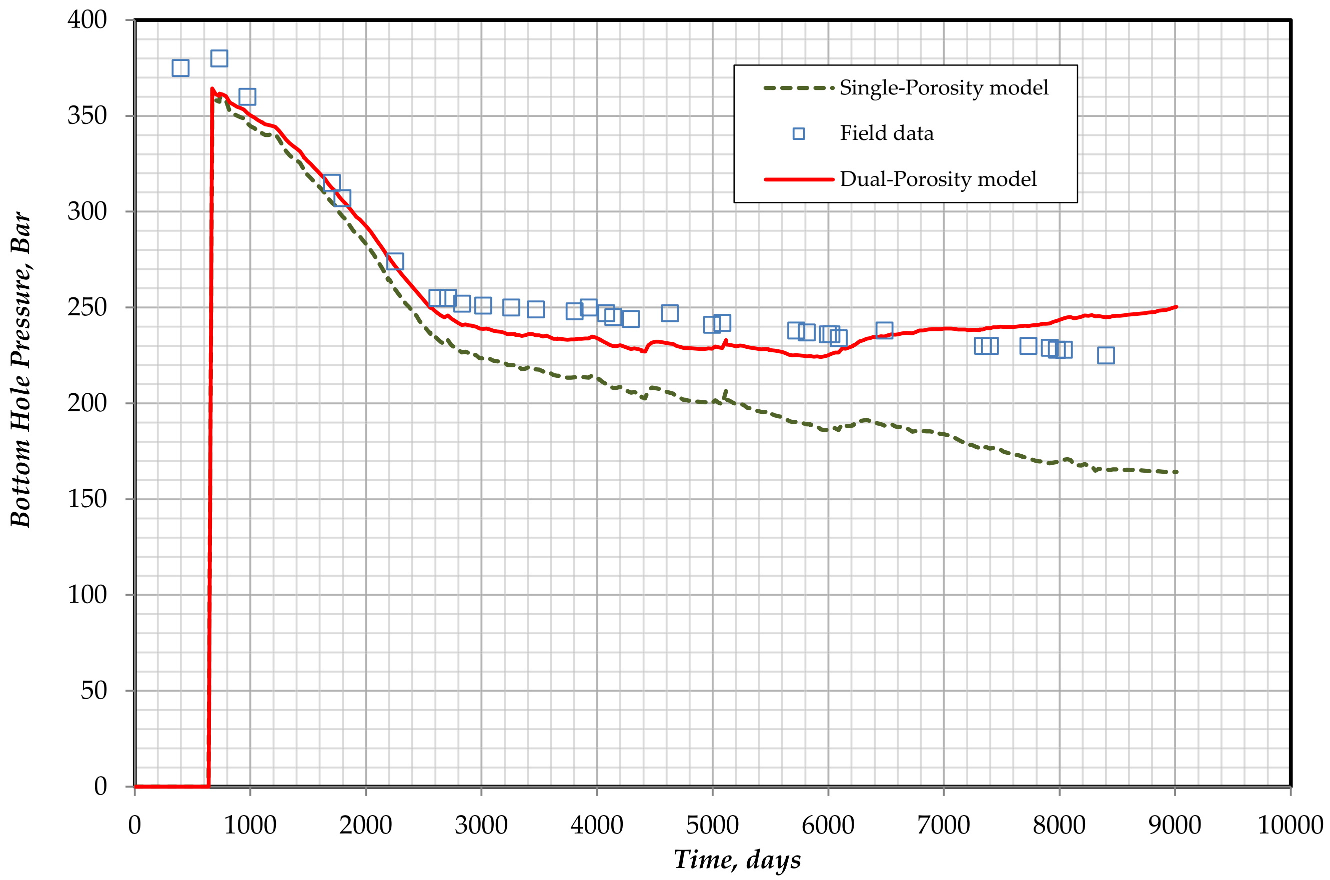


Fig.12. Comparison results for bottom hole pressure in well X2

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Разработка модели двойной пористости для трещиноватого коллектора «Белый Тигр» («Bach Ho»)

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Реферат

В статье рассматривается подход к разработке модели двойной пористости для трещиноватых коллекторов путем интегрирования параметров сравнительно хорошо откалиброванной модели с одинарной пористостью и других имеющихся данных. Параметры пористости и проницаемости для модели двойной пористости (эффективные параметры трещиновато-пористой среды) были получены процедурами разбивки параметров модели с одинарной пористостью. Остальные параметры модели двойной пористости могут быть определены на основе геологических и петрофизических данных, анализов керна или теоретических данных. В статье представлены результаты применения данного подхода для трещиноватого коллектора «Белый Тигр» («Bach Ho») во Вьетнаме. Результаты успешной адаптации модели к данным коллектора, полученные в течение длительного периода времени, демонстрируют преимущество предлагаемого подхода.

«Ağ Pələng» («Bach Ho») çatlı kollektor üçün ikiqat məsaməlilik modelinin işlənməsi

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Xülasə

Məqalədə nisbətən yaxşı kalibrləşdirilmiş birqat məsaməlilik modelin və digər mövcud məlumatların (göstəricilərin) parametrlərinin inteqrasiyası yolu ilə çat-çat kollektorlar üçün ikiqat məsaməlilik modelinin işlənməsinə yanaşmaya baxılır. İkiqat məsaməlilik modeli üçün məsaməlilik və keçiricilik parametrləri (çat-çat məsaməli mühitin effektiv parametrləri) birqat məsaməlikli modelin parametrlərinin bölünməsi prosedurları ilə əldə edilmişdir. İkiqat məsaməlilik modelinin qalan parametrləri geoloji və petrofiziki məlumatlar, kernin analizi və nəzəri məlumatlar əsasında müəyyən edilə bilərlər. Məqalədə Vyetnamda «Ağ Pələng» («Bach Ho») çat-çat kollektoru üçün bu yanaşmanın tətbiqinin nəticələri təqdim edilmişdir. Kollektorun uzun zaman dövrü ərzində alınmış məlumatlarına (göstəricilərinə) modelin uğurlu adaptasiyasının nəticələri təklif edilən modelin üstünlüyünü nümayiş etdirir.