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Application of cluster models to describe oil production from unconventional reservoirs in Bach Ho field

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ABSTRACT

Unconventional oil (tight oil) is oil trapped in low permeability sandstone, and also is a resource with great potential as it is heavily supplementing oil production from Bach Ho oil field. The tight rock must be stimulated artificially to perform fractures before the production of the oil from the fractured systems. When hydrocarbons are produced, the flow is influenced by the fracture, the stimulated rock, and the matrix rock. The initial decline of a fractured reservoir is faster than the initial decline of a conventional reservoir, and the late time decline of a fractured reservoir is slower than that of a conventional reservoir. Fractured systems have this unconventional flow behavior because of flow regimes, including: fracture linear flow, bilinear flow, formation linear flow, and pseudo-radial flow. In this paper, production behaviors of the Bach Ho Oligocene oil reservoirs are summarized and analyzed. Production rates from a tight oil reservoir are modeled using a cluster serial flow simulator that models the singlephase flow of a slightly-compressible oil. These models can succeed where the analytical models and complex simulations fail by providing estimations for physical parameters, managing uncertainty, and having fast run times.

1. Introduction

Unconventional oil is light crude oil contained in low permeability formations, including but not limited to shale. The oil itself requires very little refinement, and existing surface infrastructure can often be utilized, which reduces both surface impact and capital investment. In Bach Ho field, tight oil resources are extensively distributed and the total reserves is two times of the hydrocarbon resources granitic basement reservoirs.

Oil production performances are investigated, especially the Lower Oligocene sandstone reservoirs in Bach Ho field. Results show that gas and oil or water and oil are co-produced at an early stage of production, and many tight oil producers have seen that water cut remains constant or undergoes reduction within the first 12 months (Vietsovpetro, 2013). Tight oil production drops quite a lot in the first year of production. Reservoir simulations runs help to Fig. out what factors affect tight oil production.

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Darcy's law can be used to evaluate enhanced oil recovery potential. Ultimately, results show that the rate of oil recovery in tight oil reservoirs is sharply increased by enlarging a contact area, improving oil relative permeability, reducing oil viscosity and altering wettability.

Hydraulic fracturing is capable to boost well productivity by enlarging contact areas between wells and target formation. The advanced knowledge of stimulation needs to be emphasized in: post-fracturing monitoring with a production analysis, sweet spots identification, complex conductive fractures network creation, fracturing fluid recovery, formation damage control and permeability enhancement. As primary recovery in tight oil reservoirs is quite low, the multistage fracturing technology is a necessity and must be conducted based on a deep understanding of petrophysical and geomechanical properties. Fractured systems have this unconventional flow behavior because of flow regimes, that are fracture linear flow, bilinear flow, formation linear flow, and pseudo-radial flow.

When hydrocarbons are produced in fractured systems, the resulting flow is influenced by the fracture, the stimulated rock, and the matrix rock. The initial decline of a fractured reservoir is faster than the one of a conventional reservoir, and the late time decline of a fractured reservoir is slower than that of a conventional reservoir.

The methods used to model fractured flow can be broadly divided into three groups: analytic models, complex simulations, and cluster models. The typical analytic models (Arps, 1945) which were used to model fractures are the Arps decline curve analysis (1945) and Valko's stretched exponential method. While these analytic models do a good job matching the flow regimes, no estimations for reserves or fracture parameters can be gained by working with these analytic models. Complex simulations can also yield good modeling of the data. But complex simulation has key weaknesses (Timur, 2008) such as insufficient geological data, inadequate knowledge about the fracture system, and the computing power demand is large. Cluster models can succeed where the analytical models and complex simulations fail by providing estimations for physical parameters, managing uncertainty, and having short running time.

The cluster model selected for this study includes three models that describe the production from fractured systems were developed: 4-Tank Model, 2-Tank Model, and 3-Tank Model. These models were used to model real production data from a fractured tight sandstone play in Bach Ho field.

2. Flow regimes

When hydrocarbons are produced in fractured systems, the resulting flow is influenced by the fracture, the stimulated rock, and the matrix rock. This unconventional flow characteristic is likely because the different flow regimes that exist in fractured systems. In this section factors that affect flow regimes and evidence of flow regimes are discussed.

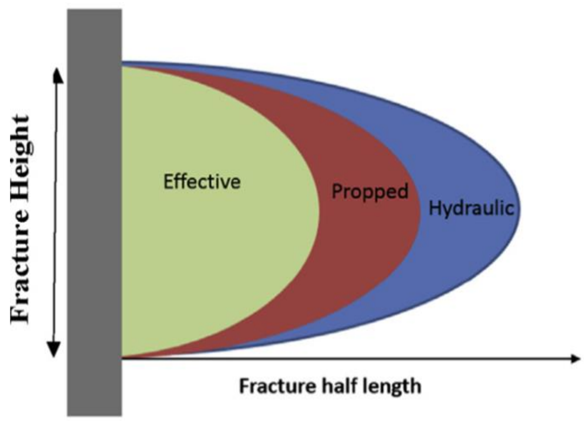

Fig. 1. Finite conductivity of a vertical fracture.

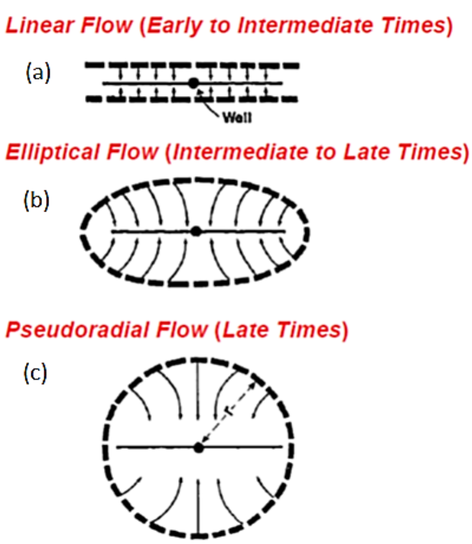

Fig. 2. Flow periods for a vertical fracture.

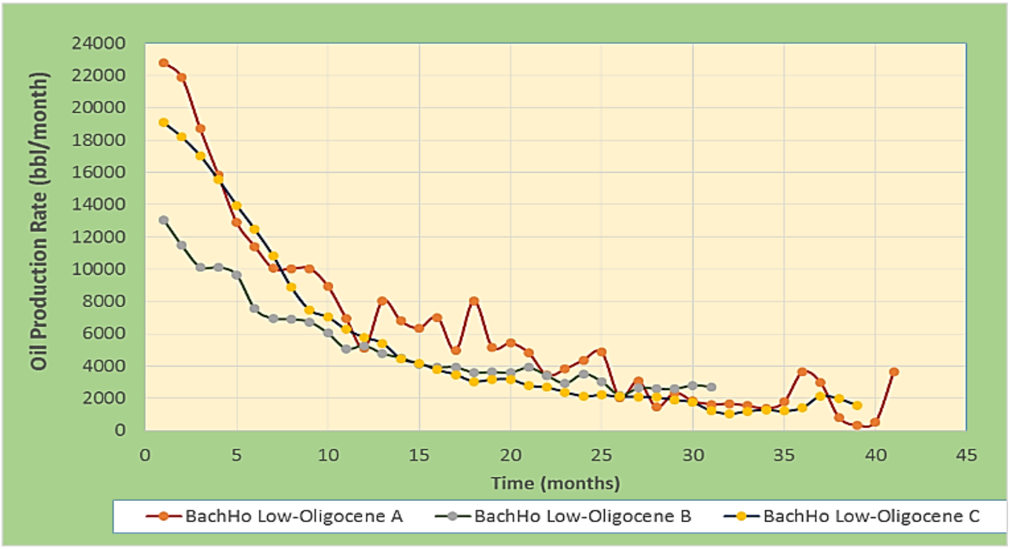

Fig. 3. Monthly oil production profiles of tight oil reservoirs in Bach Ho field.

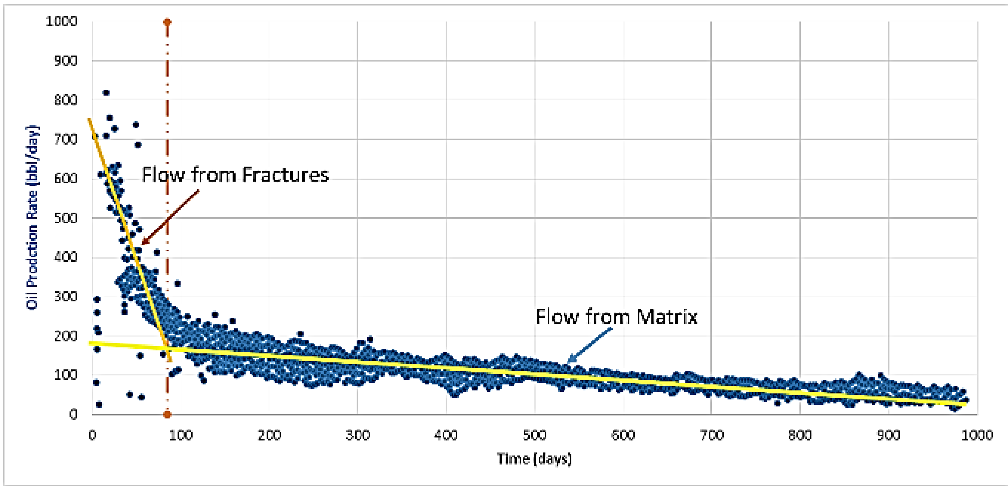

Fig. 4. Oil production rate vs. time from well BH-P.

Single bi-wing fracture systems can be visualized as in Fig. 1. Such a system would have a wellbore, a bi-wing fracture growing from the wellbore, and matrix rock around the entire system. The fracture would have dimensions of: *fracture width-*b_f, *fracture half length-*x_f, and *fracture height-h*. Ideally, the fracture in this system should have a much greater permeability than the matrix rock. When such conditions are met, the flow will exhibit four distinct flow regimes: fracture linear flow, bilinear flow, formation linear flow, and pseudo-radial flow (Cinco-Ley, 1982):

Linear flow is the superposition of fracture flow and linear flow into the fracture from the surrounding rock (see Fig. 2-a). Fracture linear flow can be determined as the straight line portion on a Change in *pressure vs. fourth root of time* (Δp *vs* $\sqrt[4]{t}$) plot using a semi log axis; this would mean a ¼ unit slope on a Change in pressure vs time plot (Δp *vs* t) using a loglog axis.

Formation linear flow is the flow that is dominated by the linear flow of fluid into the fracture (see Fig. 2-b). Formation linear flow can be determined as the straight line portion on a Change in pressure vs. square root of time (Δp vs $\sqrt{t}$) plot using a semi log axis; this would mean a ½ unit slope on a Change in pressure vs time plot (Δp vs t) using a log-log axis.

Pseudo-radial flow occurs when the drainage from the formation linear flow expands into a nearly radial shape (see Fig. 2-c).

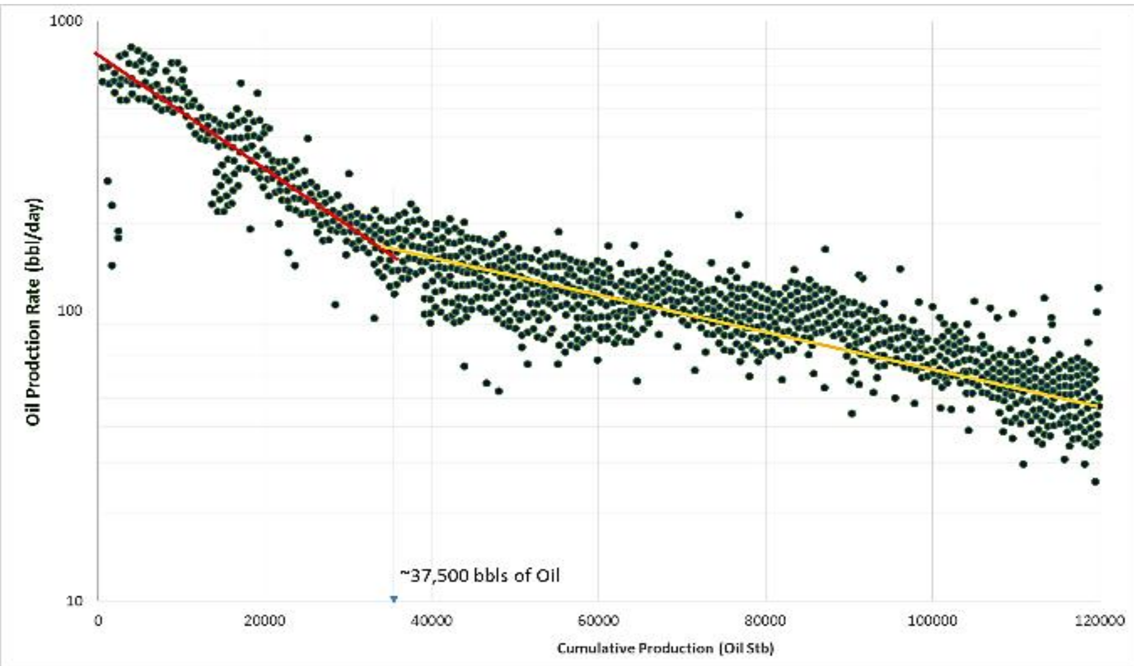

Fig. 5. Oil production (Log Scale) vs. cumulative oil produced (Linear scale) from well BH-P.

Pseudo-radial flow can be determined as the straight line portion of *Δp* vs log(t) plot; this would mean an unit slope on a Change in pressure vs time plot (*Δp* vs *t*) using a log-log axis.

As discussed earlier, these flow regimes are most evident when plotted in a *loglog Δp vs t plot*. In a study to analyze production data from tight oil wells, plots *Productivity index(J) vs t*; where *J* is defined as: $J = \Delta P/q$, where *q* is production rate and ΔP is the pressure drop.

3. Production characteristics

Fig. 3 shows the well production profiles for selected wells from four major Low Oligocene oil reservoirs. Initial rates are quite high, but they decline quickly and stabilize at low decline rates after about 9 to 12 months. The economics of tight oil development benefit from these higher initial production rates and low upfront investment. One of the most active developers of tight-oil plays, estimates that at an oil price of $US55 (WTI) and the internal rate of return for these plays can range from 30 to 70 per cent. Payout times are relatively short, varying from six months to one year.

In the oil production vs. time plot (Fig. 4), two linear segments can be observed; a steep decline up to approximately 90 days, and a less steep decline after 90 days. We have studied similar graphs on the *E* Formation and concluded that the fast (early) decline is fracture dominated and the slower (later) decline is matrix dominated. The stimulated volume is likely to have a much greater permeabilty than the matrix so it makes sense that 2 flow regimes are seen.

Linear decline in the oil production rate (log scale) vs. time (linear scale) plot is associated with exponential decline.

At the 90th day, when 37,500th barrel of oil had been produced from this well (cumulative production), is approximately the time when the flow regime changes. This becomes important when looking at Fig. 5.

In Fig. 5, two linear segments can again be observed. The flow regime changes at approximately 37,500bbls of cumulative oil produced; fast decline rate before 37,500bbls and slower decline rate after 37,500bbls. The cumulative oil production associated with the change in flow regime is when the date where the flow regime changes in Fig. 4.

A linear decline in the oil production rate (log scale) vs. cumulative production (linear) plot is associated with harmonic decline.

The total fluid (water and oil) production (log scale) vs. total fluid cumulative production (linear scale) plot (Fig. 6).

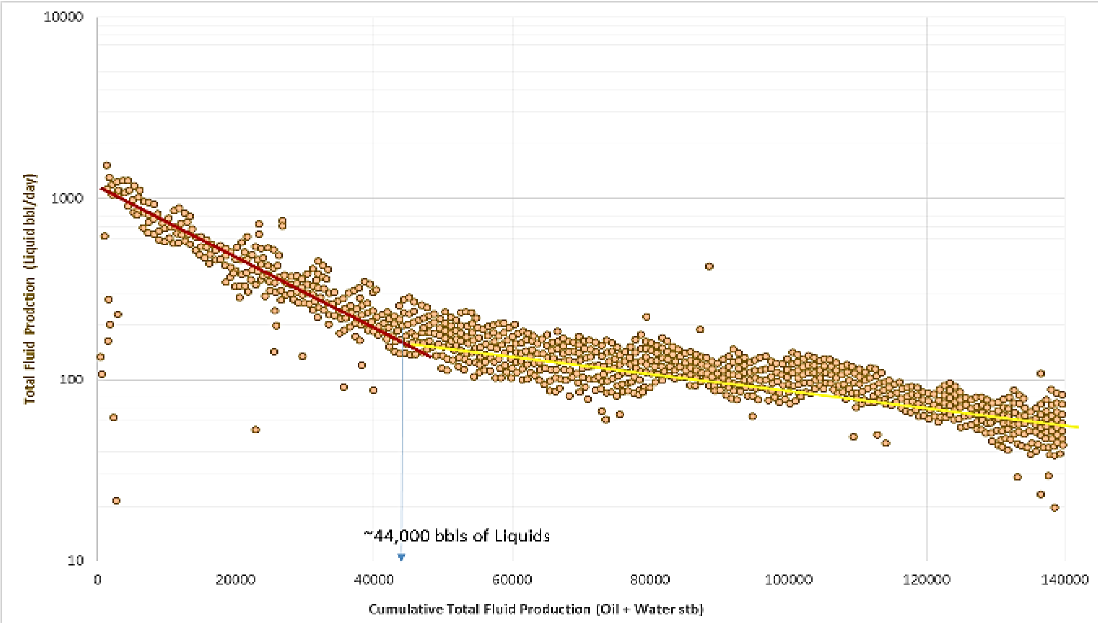

Fig. 6. Total fluid production (Log scale) vs. cumulative total fluid (Water and oil) production (Linear scale) from well BH-P.

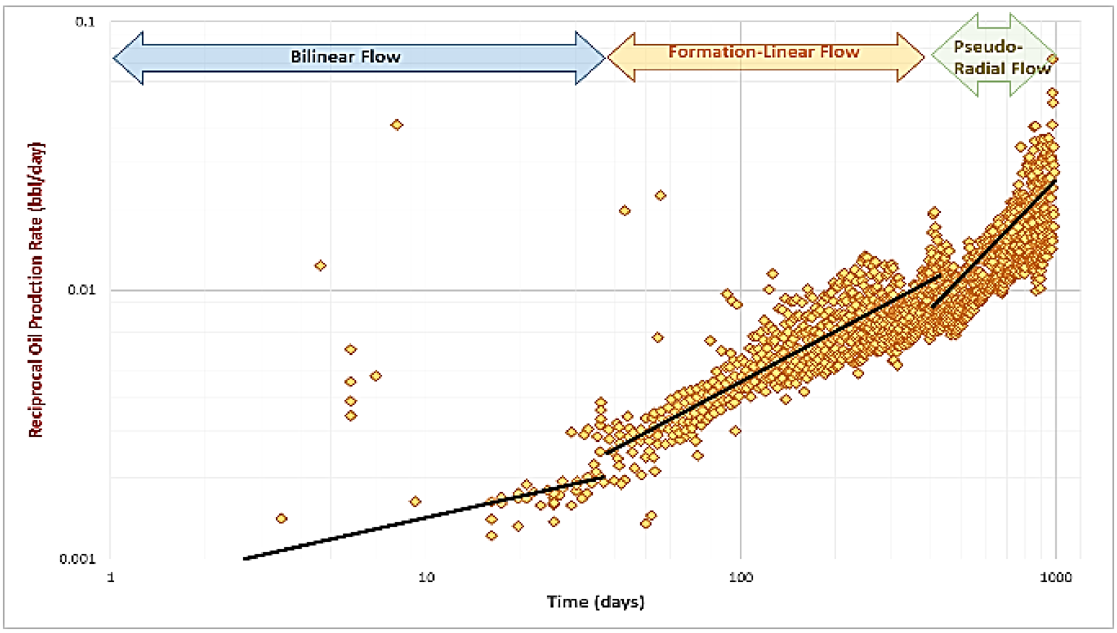

Fig. 7. Log - log scale of reciprocal oil production vs. time from well BH-P.

The 90th day of production corresponds to 44,000bbls of cumulative total fluid production, at that number the trends of fast and slow declines are consistent with observations made from Fig. 4 and 5.

The method discusses the flow regimes that should be seen in fractured flow(Cinco-Ley, 1982; Cinco-Ley et al., 1987); at early time, fracture linear flow marked by a half slope on the $1/J$ vs. time plot is dominant, bilinear flow marked by a quarter slope on the $1/J$ vs. time plot follows the fracture linear flow, formation linear flow marked by a half slope on the $1/J$ vs. time plot follows the bilinear flow, and pseudo-radial flow marked by a full slope on the $1/J$ vs. time plot follows the formation linear flow. The alteration from reciprocal productivity index vs. time to reciprocal oil production vs. time was made as bottom hole pressure data and average pressure data were unavailable.

Although the reciprocal oil production vs. time plot is not the method prescribed by (Cinco-Ley, 1982), the linear segments with the quarter half and full slopes can be seen in the data. The quarter slope is associated with bilinear flow, the half slope with formation linear flow, and the full slope with pseudo-radial flow as visualized in Fig. 2. The fracture linear flow associated with a half slope is missing in Fig. 7.

From the observation of straight line sections in the oil production rate (log) vs. time (linear) plot and the observation of the straight line sections in the oil production (log) vs. cumulative production (linear) plot, it is plausible to think that this type of production can be modeled as two or more tanks producing oil from one after another.

4. Cluster Models

The conceptual model for the 4-Domain model is that the oil will originate in the tight rock (4), flow to a slightly stimulated volume (3), flow to highly stimulated volume (2), and then flow into the propped fractures(1)/wellbore where it is produced. The following Fig. 8 and Table 1 describe the expectations for each of the domains.

The "series" model fits for all of the models (4-Domain Model, 3-Domain Model) are consolidated in this section. Only the plots that illuminate information about the changing flow regime were plotted. Daily production data and models from well BH-P were chosen to be plotted as it is representative of the daily production data; well BH-P had regions which demonstrate smooth decline behavior, a jump, and regions with scatter.

Both of the models were able to consistently fit the production data. The models are able to capture the first flow regime change which occurs at approximately 90 days of production; the models match both the fast decline rates before 150 days and slow decline rates after 90 days.

The 3-Domain Model appears that Domain-1 does contribute little to the late time flow behavior as it has a small pore volume and high permeability. The 4-Domain model often makes results that were not unique.

In Fig. 10, the same models from Fig. 9, is plotted on an oil production rate (log scale) vs. cumulative oil production (linear scale).

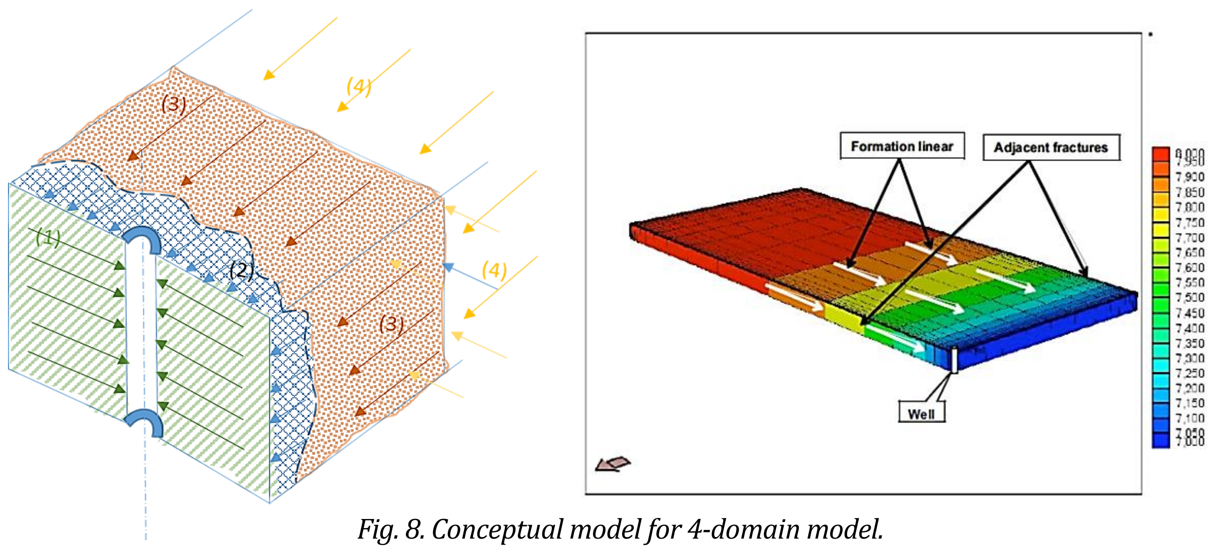

Fig. 8. Conceptual model for 4-domain model.

Table 1. Domain parameters.

	Dimentions (m)	Porosity	Permeability (mD)	PV (m3)
Domain-1 (Fracture)	Xf = 200; bf = 0.005	0.3	100 - 800	200
Domain-2 (Slightly stimulated)	40	0.1	25 - 30	280,000
Domain-3 (Highly stimulated)	50	0.07	10	1,100,000
Domain-4 (Tight rock)	200	0.06	1.0	6,000,000

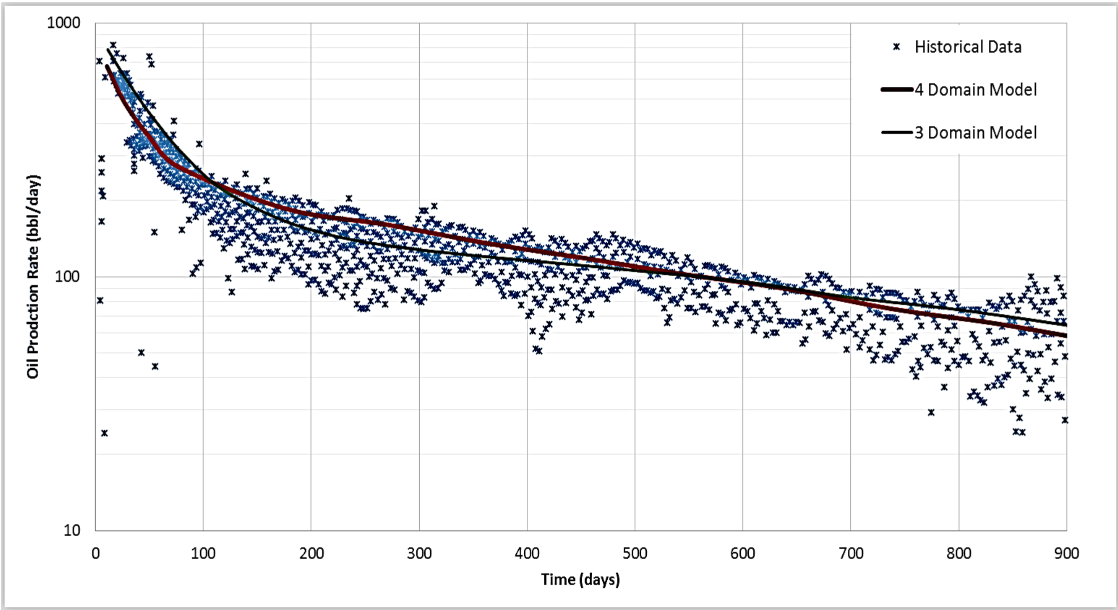

Fig. 9. Models fitted to oil production rate (Log scale) vs. time (Linear scale) from well BH-P.

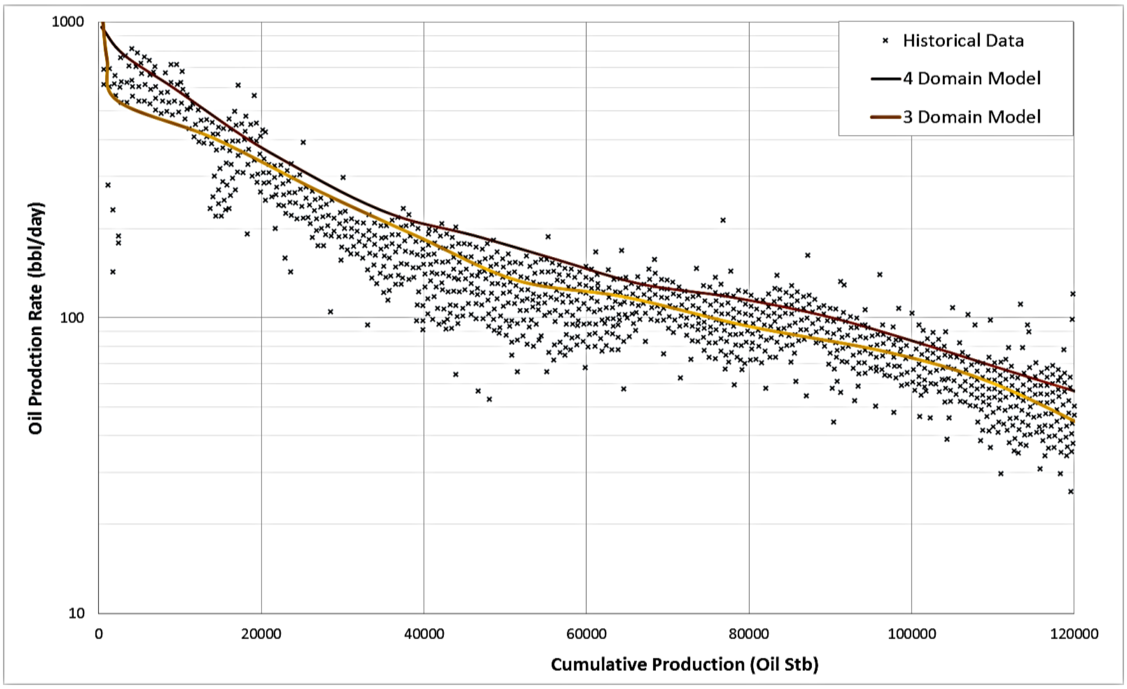

Fig. 10. Models fitted to oil production rate (Log scale) vs. cumulative oil production (Linear scale) from well BH-P.

In the 3-Domain Model, the effect of domain-1, which models the fracture volume, is accentuated in Fig. 10. At the start of production, the 3-Domain Model experiences a more vertical drop in oil production where none of the other models do.

The data from these wells often seem like there are two straight line sections in the production rate (log scale) vs. cumulative oil production (linear scale) plots while the models give combined sets of downward sloping curves. The models are downward set of curves as the series model is tanks undergoing exponential decline connected in series. Although the

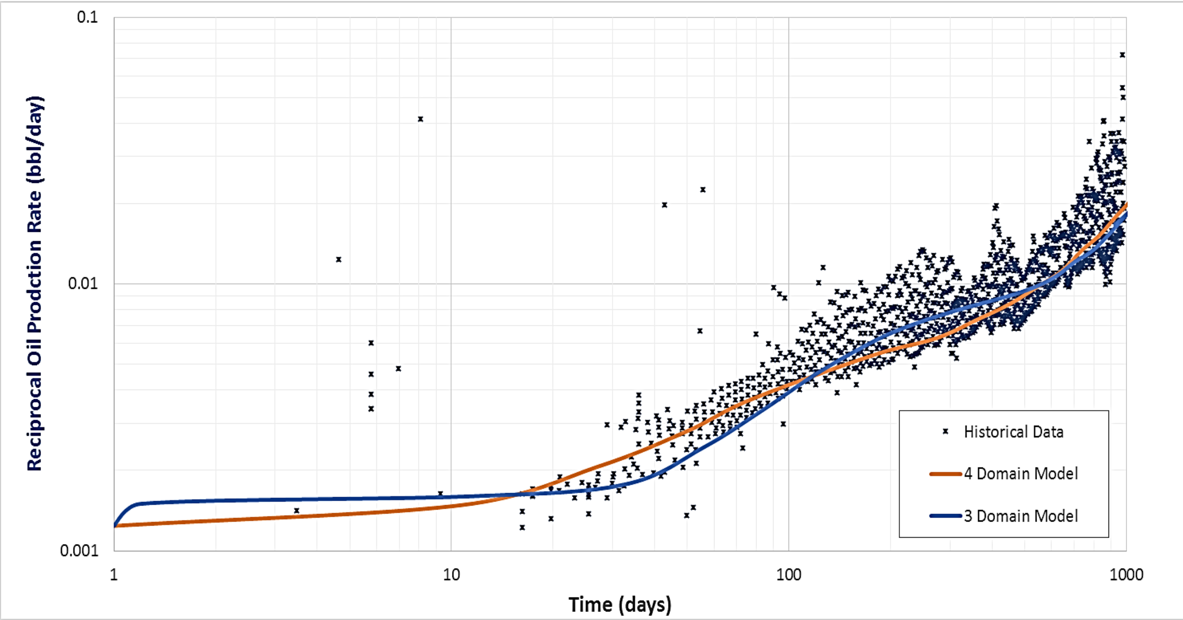

Fig. 11. Models fitted to reciprocal oil production rate (Log scale) vs. time (Log scale) from well BH-P.

difference in production may be small in the early time, the ultimate recovery estimations may be conservative with the series model if the data continues to be linear at very late time.

In Fig. 11 the same models from Fig. 9 are plotted on a reciprocal oil production rate (log scale) vs. time (log scale).

The models again match the data well. Although the models are not straight line segments, the models bend and approximate the flow regimes.

The effect of domain-1 in the 3-Domain Model is seen in Fig. 11 as the rapid rise of the reciprocal of oil production. That means fast decline in oil rate. This rapid rise is not observed in data; it is likely that this rapid rise associated with the formation linear flow occurs too quickly to be seen in the data.

5. Conclusion

Daily production data, and well summary data from a fractured tight sandstone of Bach Ho field were investigated in this study in order to use a cluster model to describe such data. Also, the simulator uses physical properties that give estimations for pore volumes. Pore volume estimations cannot be done with the fitting parameters of typical decline curve analysis.

The 4-Domain Model was developed from the observation that only four tanks were needed to simulate the production during the pre-modeling study. The modeled production matched the production data well and matched the times when the flow regimes changed. However, the solutions to simulations done using the 4-Domain Model are not unique. Several points are highlighted as follows:

The models are not perfectly straight in the oil production rate (Log Scale) vs. cumulative oil production plots where the data appears to be straight. This is to be expected as a single tank flow model would result in an exponential decline (which does not have a straight line on the oil production rate (Log Scale) vs. cumulative oil production plot). This should not be a big problem when modeling fractured oil flow as the "bend" in the model at late time can be mitigated with a large cell pore volume with a small transmissibility.

The Domain-1 which models the fracture volume causes the production rate to decline very rapid at the start of the production. This is evident when compared to other models. This rapid decline causes the 3-Domain Model to have a noticeably different production profile at early times.

At late times the models did not match each other. This difference is likely because there is more data scatter at late time data.

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