CSCanada
Advances in Petroleum Exploration and Development
Vol. 5, No. 1, 2013, pp. 63-70
DOI:10.3968/j.aped.1925543820130501.1068

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

Analysis of Oil Production Behavior for the Fractured Basement Reservoir Using Hybrid Discrete Fractured Network Approach

J. J. Han[a]; T. H. Lee[a]; W. M. Sung[a],*

[a] Petroleum & Natural Gas Engineering Lab., Department of Natural Resources and Environmental Engineering, Hanyang University.
* Corresponding author.

Supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by Korea Government Ministry of Knowledge Economy (No.2010201010092A).

Received 1 January 2013; accepted 14 March 2013

Abstract

Unlike naturally fractured reservoir, fractured basement reservoir (FBR) has almost non-permeable matrix and flow is strongly dependent upon fracture network. This might cause the rapid changing behavior on oil production whether fracture near wellbore is saturated with either oil or water. In this aspect, realistic representation of fracture network is essential in FBR. Therefore the simulation of FBR is generally applied by dual-porosity (DP) continuum approach because discrete fractured network (DFN) simulator with multiphase flow is not commercially available except in-house model.

In this paper, hybrid DFN approach is applied, which is continuum model coupled with local grid refinement (LGR). LGR is adapted at the cells which are passing through fractures, in order to represent fracture width less than 0.1 ft. Up to now, LGR is mostly used for well block rather than the fracture. In this approach, well control volume can not be described by LGR cell, thus, four-leg horizontal well concept substitutes the vertical well with the use of equivalent wellbore radius for overcoming the numerical convergence problem. The application of hybrid DFN approach for FBR is discussed about investigation of the possibility for drastic change on oil production. Based on the results, in fractured reservoir using hybrid DFN approach, oil production is not found to be proportional to the magnitude of matrix permeability, not as in porous system with dual-porosity approach. Also, we realized that oil production is once dropped it can not be recovered back to previous level in FBR. This is because oil-saturated fracture near well is once changed to water-saturated, then, there was not anymore changes occurred within the same fracture.

Key words: Dual-porosity; Hybrid DFN; Fractured basement reservoir; Local grid refinement

Han, J. J., Lee, T. H., & Sung, W. M. (2013). Analysis of Oil Production Behavior for the Fractured Basement Reservoir Using Hybrid Discrete Fractured Network Approach. *Advances in Petroleum Exploration and Development*, *5*(1), 63-70. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/j.aped.1925543820130501.1068
DOI: http://dx.doi.org/10.3968/j.aped.1925543820130501.1068

NOMENCLATURE

B : formation volume factor, rb/stb
k_m : absolute permeability of matrix, md
k_f : absolute permeability of fracture, md
k_r : relative permeability
k_{ro} : oil relative permeability
k_{rw} : water relative permeability
P : Pressure, psia
P_C : capillary pressure, psi
Q_O : oil production rate, stb/day
S_O : oil saturation
S_W : water saturation
Φ : porosity

ABBREVIATION

BHP: bottomhole pressure
DFN: discrete fractured network
DP: dual-porosity
FBR: Fractured basement reservoir
LGR: local grid refinement
WC: water cut

INTRODUCTION

The fractured basement reservoirs have been concentrated as the primary target for hydrocarbon production since the mid-1990s. The Cuu Long Basin in offshore Vietnam may be the best known fractured basement reservoir. The Cuu Long Basin comprises 95% of hydrocarbon production in Vietnam, and 85% of that comes from fractured granitic basement (Geo Science Limited, 2010).

The FBR have highly complex fracture networks and heterogeneity that is created through the processes of tectonic deformation, cooling, hydrothermal activity, and weathering. Reservoir quality and production from granitic basement usually rely on the presence of a connected open-fracture network because matrix porosity and permeability are extremely low, typically ø<0.5% and <10~11 cm^2, respectively. Production from these reservoirs, which are characterized by high permeability along the fractures and negligible intergranular matrix porosity, is very sensitive to production rates (Park *et al*., 2005). Therefore, in a fractured basement reservoir, the fracture often controls the hydraulic flow as a conductor. However, due to the presence of highly complex fracture networks, these reservoirs generally show higher flow rates at first and then rapidly reduced production. Therefore, it is difficult to predict production performance and control management of the reservoir fluids. To express the flow behavior of these reservoirs, various models have been developed, such as dual-porosity and discrete fractured network models.

The dual-porosity continuum approach is often used to simulate fractured reservoirs. This model overlaps the fracture and the matrix. They are connected to each other through an exchange term that links each fracture cell to its corresponding matrix cell in a grid block. However, the model represents an overly simplistic view of a geologically complex reservoir. Thus, the DP continuum approach cannot be applied to disconnectedly fractured media and cannot represent the heterogeneity of a highly complex system. Discrete fractured network approach is free of the limitations of the DP continuum approach. They have been advanced to describe various phenomena at the microscopic, macroscopic, and even larger scales (Muhammad Sahimi, 2011) and can describe fractured reservoirs more realistically. However, although DFN approach has evolved over the past years, the existing commercial DFN approach can not describe the flow of multi-phase fluids.

In this analysis, we performed the simulation using a hybrid DFN approach that can reflect complex fracture networks. This paper presents the numerical results of flow behavior using the model based on the hybrid DFN approach with local grid refinement in FBR. Moreover, the results of production behavior for the hybrid DFN system are compared to DP system for FBR.

1. FRACTURED BASEMENT RESERVOIR SYSTEM

In this analysis, we generated a two-dimensional fractured basement system by using a hybrid DFN approach, as shown in Fig. 1.The fracture network model is a FBR containing an oil–water system. This system is connected with an aquifer as part of the oil reservoir (Figure 1).

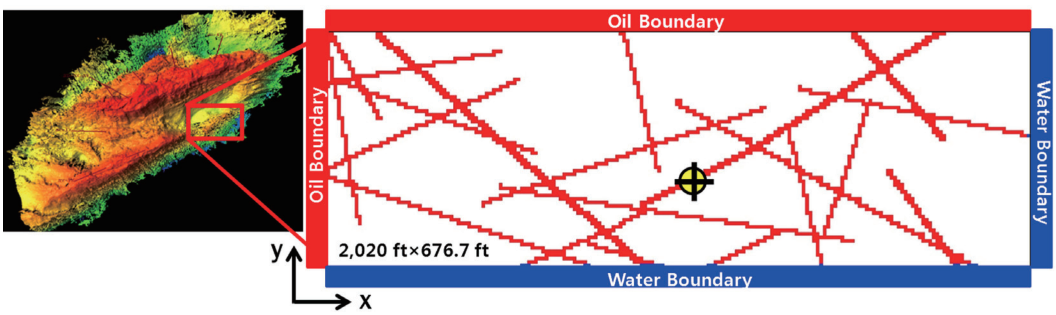

Figure 1
Reservoir System

The fracture networks are composed of 19 major fractures that have a fracture aperture of 0.1 ft. We applied LGR for 3×3 cells to describe more realistic fractures for all of fracture cells. The permeability of the fractures (kf) is 2000 md and that of the matrix (km) is 0.1 md, assuming almost no flow. These fractures are 100% saturated with oil of 43° API gravity. The viscosities of the oil and the water are 2.0 cp and 0.5 cp, respectively. Kazemi's model was adopted to represent relative permeability and capillary pressure. The mobile range of water saturation of relative permeability in the system is form 0.25 to 0.70. The capillary pressure is assumed to be the same in both the fracture and the matrix, and the capillary pressure end points are 4.0 psi, as indicated in Figure 2 (Kazemi *et al*., 1976).

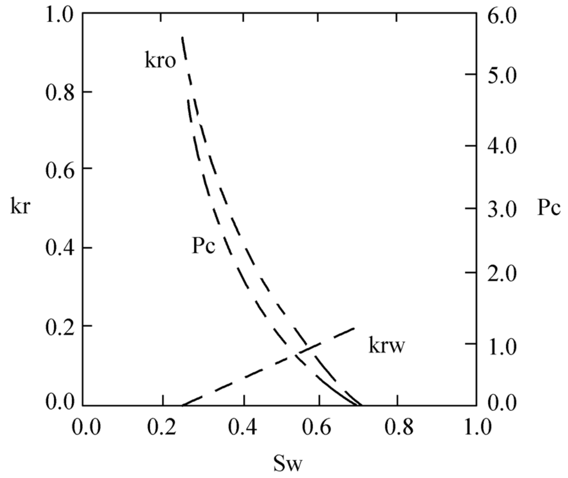

Figure 2
Relative Permeability Curves for Oil and Water and Capillary Pressure

The production well is located in the fracture near the center of the system. Since it is difficult to install a production well in an LGR system having 0.1 ft of fracture aperture at intercepted cell, we applied equivalent system of four horizontal-leg wells to correspond to a vertical well (Figure 3).

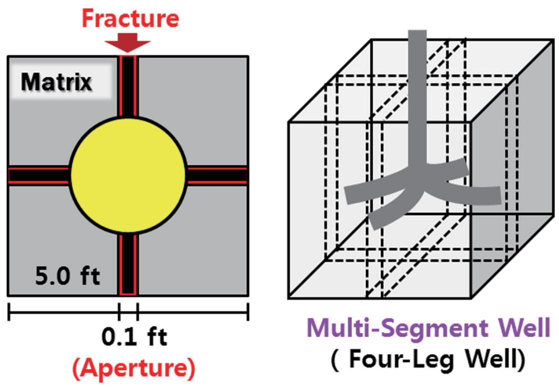

Figure 3
Well Block Description

The production well was produced at a bottomhole pressure (BHP) of 5500 psia during the production period. The other reservoir properties are given in Table 1.

Table 1
Reservoir Properties for the Simulation

Parameters	Values
Number of Global Cell [X-Y-Z]	13,400 (200×67×1)
Number of LGR Cell [X-Y-Z]	1,596 (3×3×1)
Initial Pressure [psia]	6,000
BHP [psia]	5,500
Porosity [fraction]	0.13
Matrix Permeability [md]	0.1
Fracture Permeability[md]	2000
Aperture [ft]	0.1

To be continued

Continued

Parameters	Values
Initial Oil Saturation [fraction]	1.0
Oil Viscosity [cp]	0.5
Water viscosity [cp]	2.0
B_o at 8000 psia [rb/stb]	0.9200
B_w at 8000 psia [rb/stb]	0.9760

2. RESULTS AND DISCUSSIONS

The fluids in FBR flow mainly through fracture networks because the matrix permeability of these reservoirs is extremely low. Because fluid flow through fracture network leads to sudden changes in production, we performed a simulation that is applied by using the hybrid DFN approach to understand flow behavior in the FBR. The absolute permeability of the matrix and the fracture are 0.1 md and 2000 md, respectively, and all boundary pressures maintain an initial reservoir pressure of 6000 psia. The oil-saturation distribution during 25 years of this resulting production is indicated in Figure 4. The inflow of oil into the fracture of a nearby production well is affected by inflow of water from the aquifer, because the production well is located in the fracture that is closed and is connected to the aquifer. Therefore, as shown Figure 5, the oil production rate decreased remarkably, as the water production rapidly increased after 400 days.

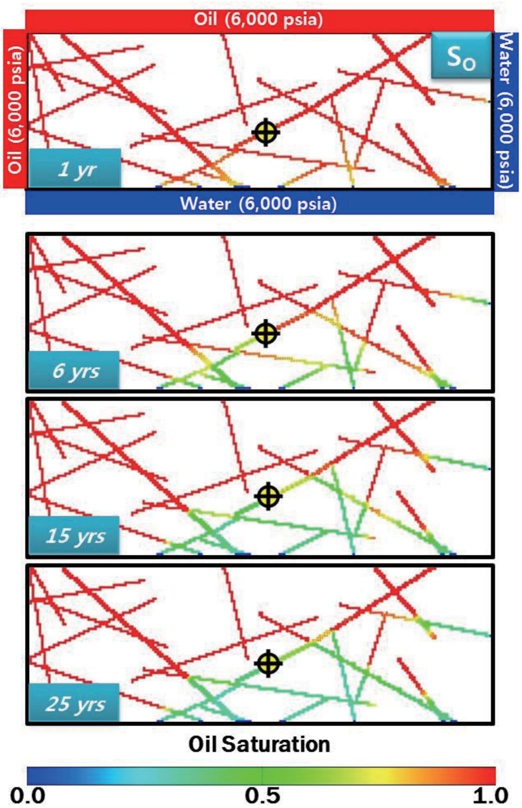

Figure 4
Oil Saturation Distributions During 25 Years of Production with Matrix Permeability of 0.1 md

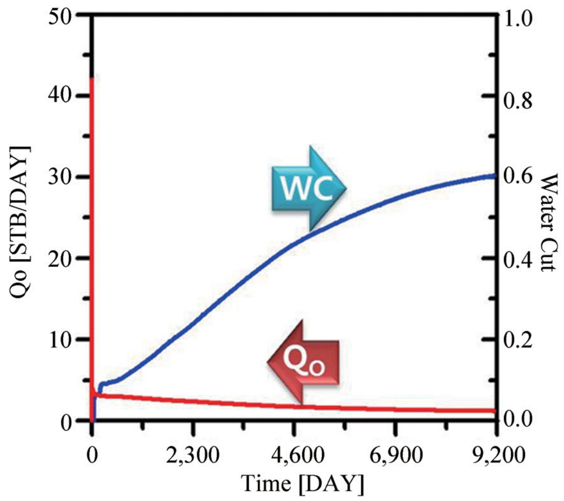

Figure 5
Oil Production Rate and Water Cut for General Case During 25 Years

To examine these phenomena in more detail, we divided area "A" and area "B" in 25 years of production (Figure 6). First, "A" is the area where oil from the upper oil boundary meets water from the lower aquifer. In this area, oil flows into the production well is obstructed by water flow, because the oil viscosity (2.0 cp) is greater than the water viscosity (0.5 cp), and the production well is located near the aquifer. Considering that such conditions were maintained for 25 years, we knew that oil flowing into the production well would not change, although the production well continued to produce after 25 years. Second, area "B" represents the dead fracture in which only one side of the fracture is connected to the other fractures. In this area, we could show residual oil that did not move after flowing into the dead fracture. Due to such disturbance between the fluids, the oil remained and the pressure did not decrease at the upper left of the system. Therefore, to extract oil trapped in FBR, an infill well must be considered at area "A" outside the influenced area of the production well, as illustrated in Figure 7.

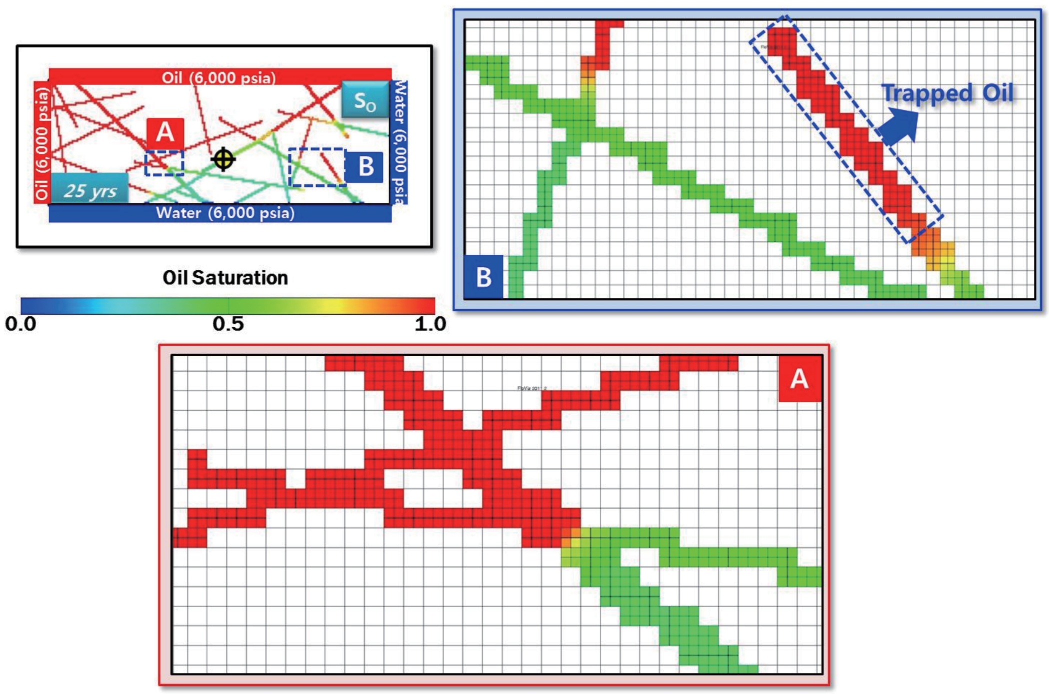

Figure 6
Oil Saturation Profiles for Areas of A and B After 25 Years

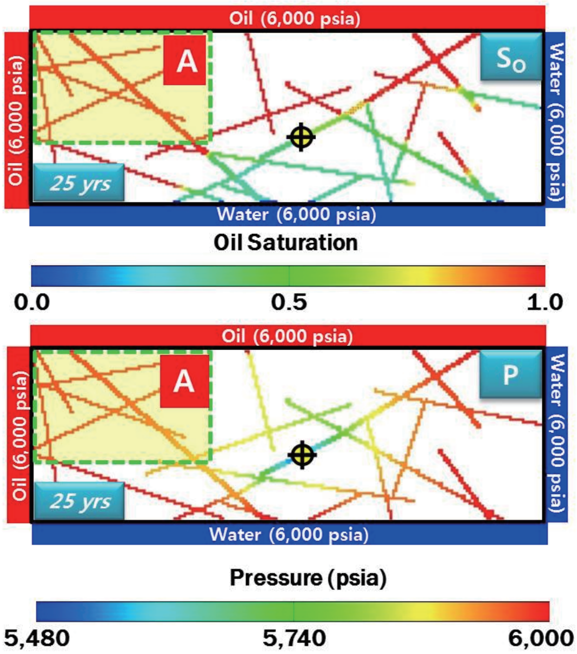

Figure 7
Location for Infill Production Well

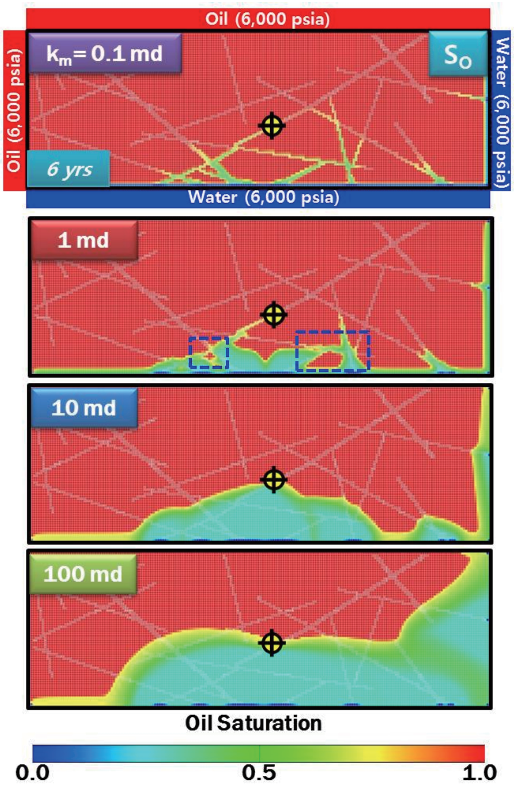

Figure 8
Oil Saturation Profile for Matrix Permeability of 0.1, 1, 10 and 100md After 6 Years

We performed the simulation by changing the absolute permeability of the matrix from 0.1 md to 100 md to determine the importance of fluid flow through the fracture according to the magnitude of the absolute permeability of the matrix. Figure 8 represents the oil-saturation distribution according to the magnitude of the absolute permeability of the matrix during six years of production. In the case of 0.1 md, the fluids flowed only through the fracture networks. Oil was bypassed at the dotted line for the case of 1 md, in which the fluids flowed into the matrix, but the amount of oil was much less than the fluids flowing through the fractures. However, fluids flowed not only through fractures but also through the matrix because of the higher absolute matrix permeability in the cases of 10 md and 100 md. Consequently, we observed an irregular water cut, instead of an increasing water cut, with increasing absolute permeability of the matrix (Figure 9). That is, water for the system of 0.1, 1.0, 10, and 100 md starts producing at the times of 63, 613, 631, and 73 days, respectively.

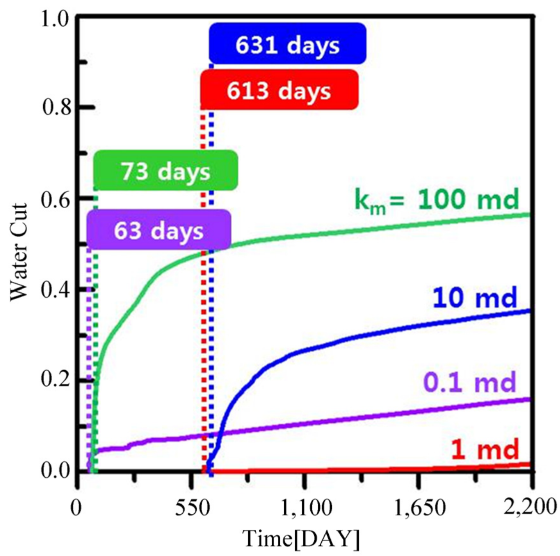

Figure 9
Comparison of Water Cut for Matrix Permeability of 0.1, 1, 10, 100 md During 6 Years

We constructed a DP system that corresponds to the hybrid DFN system to compare the two systems. Absolute permeability of the matrix and fracture in both models are 0.1 md and 2000 md, respectively. All boundary conditions are maintained at the reservoir initial pressure (6000 psia). The distribution of pressure differed remarkably after 1 year of production simulated by hybrid DFN and DP approaches (Figure 10). In the DP system, pressure decreased homogeneously around the production well. Meanwhile, the pressure decreased heterogeneously through fracture networks in the hybrid DFN system, which reflects the complexity of fracture networks. Due to this effect, oil production rate curves for these simulations showed that the hybrid DFN curve decreased more rapidly than the DP curve during early production (Figure 11). Moreover, the curves of oil production rates cross one another after 6 years. Therefore, we expect that the analytical results for the same reservoir, such as total production rate and total duration of production, may differ owing to the difference in expression between the two models for fracture networks.

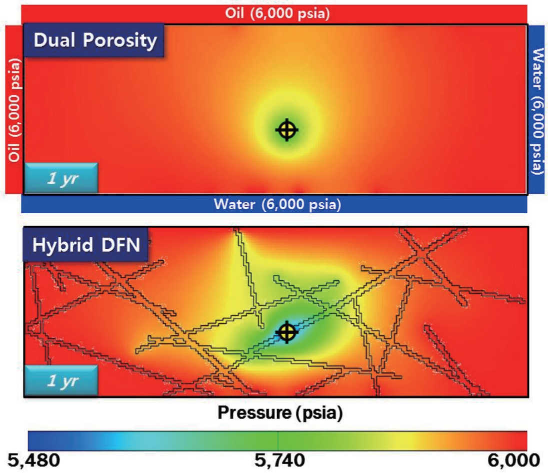

Figure 10
Distribution of Pressure After 1 Year of Production Dual Porosity and Hybrid DFN

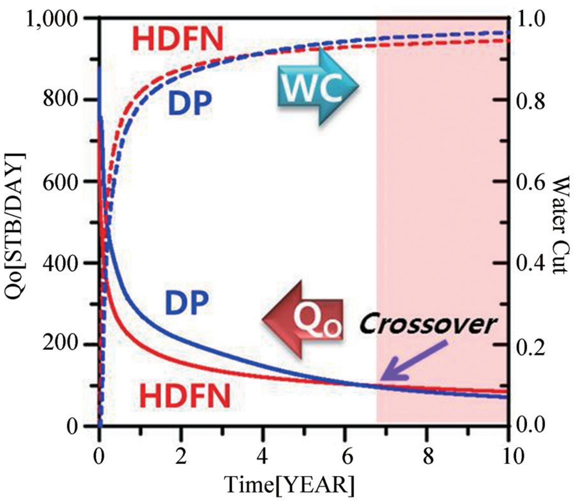

Figure 11
Comparison of Oil Production Rate and Water Cut, Calculated by Dual Porosity and Hybrid DFN

To determine the cause of rapidly changing production, which is characteristic of FBR, we analyzed which type of fluid in the fracture changes to another type of fluid according to differing boundary conditions, i.e., whether the fluid in the fracture changes from oil to water and then to oil again. Case "A" is based on the original case in which all of the boundary conditions remained at the reservoir initial pressure. Case "B" represents the depleted reservoir, which had the pressure of oil boundary condition that was lower than the pressure of water boundary condition. In case "C", the reservoir was connected with the small aquifer that had the lower pressure of oil boundary condition. In these results, all three cases showed no change in the type of fluid in the fracture once the original saturated fluid (oil) in the fracture changed into another fluid (water), according to the effect of the boundary condition (Figure 12).

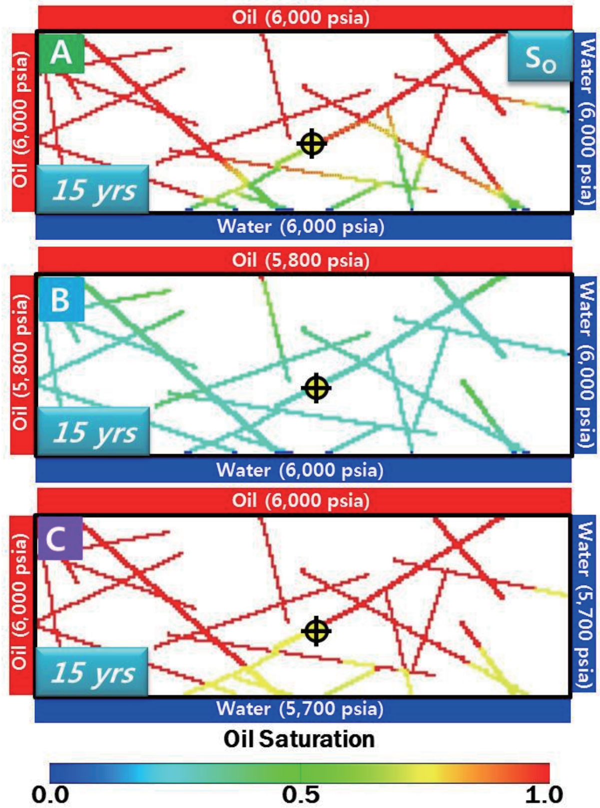

Figure 12
Oil Saturation Distributions During 15 Years of Production

Figure 13 and 14 showed that oil production in the cases of "A" and "B" showed a similar decrease. However, oil production in the case of "C" decreased after the effect of the aquifer disappeared, and then regular oil production resumed by oil flow from the oil boundary after 1.5 days. The monotonic production behavior exhibited in all three cases showed that the type of fluid in the fracture did not change after the original oil-saturated fracture became saturated by water caused by the effect of the aquifer on the FBR. Therefore, the decreased oil production behavior is not reversed by flowing water in the production well.

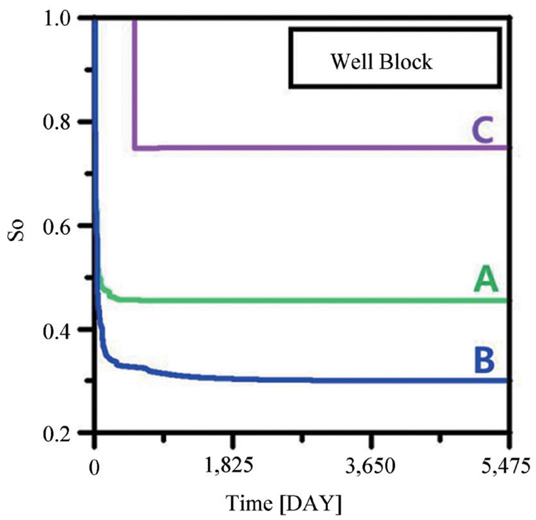

Figure 13
Oil Saturation for A, B, C Cases in Well Block During 15 Years

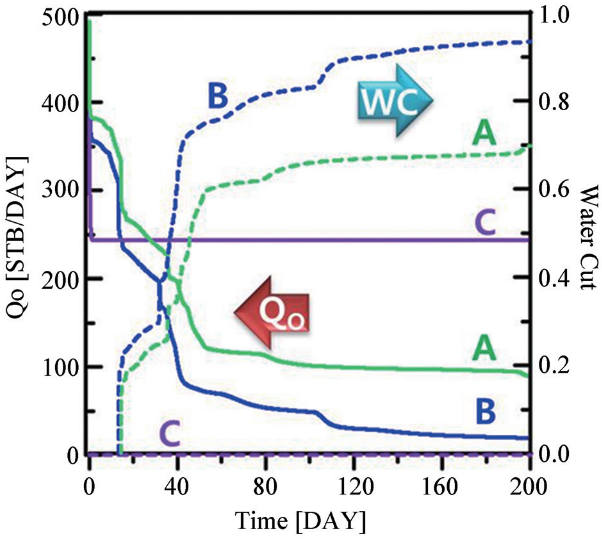

Figure 14
Oil Production Rate and Water Cut for A, B, C Cases During 200 Days

We performed simulations to observe the flow pattern of fluids under the influence of well locations for porous and fractured basement reservoirs. Figure 15 shows the oil-saturation distribution for the hybrid DFN according to well location after 10 years of production. In the case of a well located at "A", water did not flow into the upper left side of the fractures of the production well. However, in the case of a well located at "B", although the production well was located near the oil boundary, water flowed into the upper left side of the fractures of production well.

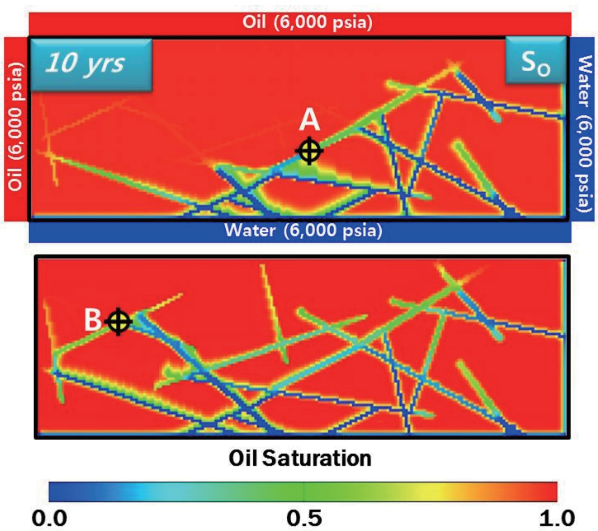

Figure 15
Comparison of Fracture Networks According to Well Location in the Basement Reservoir After 10 Years

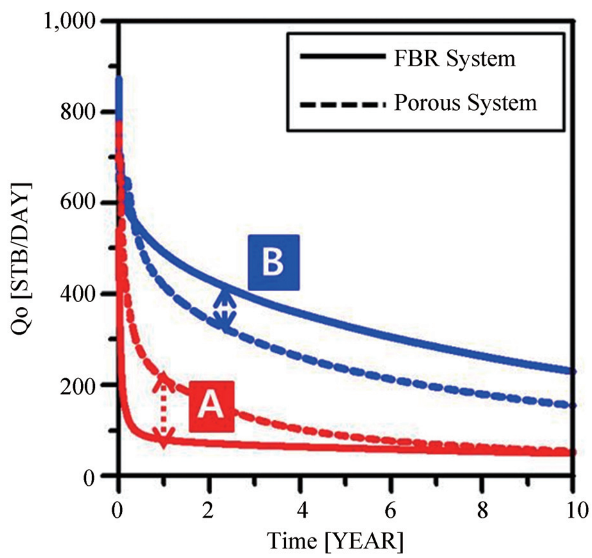

Figure 16
Oil Production Rate for the Porous Reservoir System and the Basement Fractured Reservoir System

We compared the results for a porous reservoir and a fractured basement reservoir to examine the importance of fluid flow through a fracture network. As shown in Figure 16, the oil production rates of production wells located at "A" and "B" differed greatly between the two models. Therefore, the flow behavior is significantly affected by well location, because fluid flow through fractures is predominant for a fractured basement reservoir compared to a porous reservoir.

CONCLUSION

In this study, we have attempted to examine the drastic change of oil production in fractured basement reservoir.

Hybrid DFN approach was applied by using local grid refinement method for representing the fracture more realistically in finite difference method simulator. From the results, we have drawn the following conclusions:

(1) In fractured reservoir using hybrid DFN approach, oil production is not found to be proportional to the magnitude of matrix permeability not as in porous system with dual-porosity approach.

(2) In accordance with the results of hybrid DFN comparing to DP approach, the reservoir pressure declined in a form of fracture network and consequently the production behavior can be also expected to be occurred rapid change unlike smoothing change in DP approach.

(3) We realized that oil production is rapidly dropped once, it can not be returned back to previous level in FBR. This is because oil-saturated fracture near well is once changed to water-saturated, then, these was not anymore changes occurred within the same fracture.

(4) In the influence of well location in FBR compared against porous system, it was concluded that in FBR. Well location is much more sensitive on oil production comparing to porous reservoir, since oil flows only through extremely high conductive fracture network.

REFERENCES

[1] Dang, C. T. Q., Nguyen, N. T. B., Bae, W. S., Chen, Z. & Phung, T. H. (2011). Lessons Learned and Experiences Gained in Developing the Waterflooding Concept of a Fractured Basement-Granite Reservoir: A 20-Year Case Study. Paper CSUG/SPE 137561 Presented at the *Canadian Unconventional Resources & International Petroleum Conference, Calgary*, 19-21 October 2011.

[2] Geo Science. (2010). *Hydrocarbon Production from Fractured Basement Formations* (Version 9). Geo Science Limited.

[3] Kazemi, H., Merrill, JR. L. S., & Porterfield, K. L. (1976). Numerical Simulation of Water-Oil Flow in Naturally Fractured Reservoirs. *SPE Journal*, *16*(6), 317-326.

[4] Kim, J. G., & Deo, M. D. (2000). Finite Element, Discrete-Fracture Model for Multiphase Flow in Porous Media. *American Institute of Chemical Engineers Journal*, *46*(6), 1120-1130.

[5] Kok, J. D, Neff, P., & Clemens, T. (2009). Oil Recovery from a Tight Fractured Basement Field. Paper SPE 121107 Presented at the *SPE Europec/EAGE Annual Conference and Exhibition, Amsterdam*, *Netherlands*, 8-11 June 2009.

[6] Lee, T. H., Jang, Y. H., Park, H. M., Lee, K. S., & Sung, W. M. (2011). Investigation of Water BT Phenomenon in the Fractured Basement Reservoir Contacted with Bottom Water Aquifer. Paper SPE 146874 Presented at the *Asia Pacific Oil & Gas Conference and Exhibition, Jakarta*, *Indonesia*, 20-22 September 2011.

[7] Lee, W. S., & Kim, H. T. (2011). Practical Analysis Techniques for Characterization of Naturally Fractured Reservoirs. *Journal of the Korean Society for Geosystem Engineering*, *48*(2), 211-225. Retrieved from http://site031.1004pr.kr/linker/review.php?sid=2560

[8] Lee, Y. S., Park, J. K., Seo, J. W., Kim, K. H., & Sung, W. M. (2009). A Study on 3D DFN Model Using 2D Areal Survey and 1D FMI Well Logging. *Journal of the Korean Society for Geosystem Engineering*, *46*(6), 711-720. Retrieved from http://site031.1004pr.kr/linker/review.php?sid=847

[9] Moinfar, A., Narr, W., Hui, M. H., Mallison, B., & Lee, S. H. (2011). Comparison of Discrete-Fracture and Dual-Permeability Models for Multiphase Flow in Naturally Fractured Reservoirs. Paper SPE 142295 Presented at the *SPE Reservoir Simulation Symposium*, *Texas*, 21-23 February 2011.

[10] Muhammad, S. (2011). *Flow and Transport in Porous Media and Fractured Rock*. Weinheim, Germany: WILEY-VCH.

[11] Sung, W. M., & Park, J. H. (2004). Characterization of Fractured Basement Reservoir Using Statistical and Fractal Methods. Paper SPE 90337 Presented at the *SPE International Petroleum Conference*, *Puebla*, *Mexico*, 8-9 November 2004.

[12] Seo, J. W., Lee, T. H., Lee, Y. S., Sung, W. M., & Lee, J. H. (2009). Development of 3D DFN Model with Rectangular Fracture Type. *Journal of the Korean Society for Geosystem Engineering*, *46*(4), 279-288. Retrieved from http://site031.1004pr.kr/linker/review.php?sid=807

[13] Sung, W. M., & Park, J. H. (2004). Characterization of Fractured Basement Using Statistical and Fractal Method. Paper SPE 90337 Presented at the *SPE Annual Technical Conference and Exhibition*, *Houston*, *Texas*, 26-29 September 2004.