# Investigation on the Productivity Behaviour in Deformable Heterogeneous Fractured Reservoirs

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## Introduction

Several hydrocarbon production wells in the North Sea reservoirs suffer from productivity reduction during primary production. Since the affected reservoirs are highly fractured, closure of natural/induced fractures around wells, due to effective stress increase is expected to be one of the main reasons for this reduction. Discrete fracture and matrix (DFM) modelling is selected in this investigation because of its ability to represent fracture behaviours more realistically. Moreover, it has become a preferential method for modelling flow in fractured formations for the past decade (Bisdom et al., 2017; Salimzadeh et al., 2018).

While the fracture aperture is commonly assumed to be either constant or uniformly distributed, it is well-known that the aperture distribution is heterogeneous and fluctuates with varying contact stress at each point on the fracture surface. The heterogeneous aperture field can affect the flow performance, and fracture aperture evolution due to thermo-poroelastic stresses (Guo et al., 2016). Hence, this study aims to investigate and highlight effects of fracture aperture variation, including initial stage and deformed behaviour, on the productivity of a conceptual steady-state single-fracture reservoir.

## *Methodology*

A coupled flow-deformation finite element simulator is utilised to model flow in fractured formations (Salimzadeh et al., 2018). The aperture distribution is achieved using normal and log-normal distributions. Fracture aperture is related to the contact stress using the Barton-Bandis model (Guo et al., 2016)

$$a_f = a_0 - \frac{a\sigma_n}{1 + b\sigma_n} = \frac{a}{b} - \frac{a\sigma_n}{1 + b\sigma_n}$$

where $a_0$ is the fracture aperture at zero contact stress, approximated by $a_0 = a/b$, $\sigma_n$ is the normal component of the contact stress, $a$ and $b$ are model parameters. In all cases, $a_0$ is the constant, while $a$ values are populated using normal and log-normal distributions. The parameter $b$ is calculated using $b = a/a_0$ to guarantee the same $a_0$ for all points (see input geometry parameters in Figure 1a and Table 1). Results from heterogeneous cases are compared with rigid pressure-dependent (aperture is a function of either initial or production pressure) and homogeneous deformable models (aperture at each point is calculated as a function of fracture pressure).

**Table 1: Input parameters**

| Parameter | Value | Unit |
|---|---|---|
| the initial reservoir pressure ($p_i$) and stress | 2755 and 3480 | psi |
| production pressure ($p_{wf}$) | 500, 1000, 1500 and 2000 | psi |
| mean of a & b (constant for homogeneous cases) | $5.7\times10^{-7}$ and $1.3\times10^{-3}$ | mm/psi |
| variance of a (all distributions) | $8.77\times10^{-14}$ | $(mm/psi)^2$ |
| $a_0$ (constant for all cases) | 0.45 | mm |
| matrix permeability in y-direction | 0.24 | mD |
| distance from boundaries to fracture | 200 | m |
| fluid viscosity | 2 | cP |
| fracture half-length and height | 150 and 45 | m |

## *Results and discussion*

Production rates of heterogeneity model are presented as a scattering and kernel density plot in Figure 2 for the normal and log-normal distribution cases. Each producing pressure is simulated at least for 300 heterogeneous model realisations for both distributions. The flow rates remain between the maximum, and minimum bounds, i.e. aperture as a function of initial and production pressure are upper and lower limits, respectively. Furthermore, the production rates of the models with a heterogeneous aperture are always greater than that of the model with a homogeneous aperture. As shown in Figure 2c, flow channellings (white arrows) occur and act as a short-circuit between the fracture boundaries and the production well. However, in the homogeneous case, the minimum aperture values are around the production well, which resulting in hindering the fluid flow.

In summary, results show both heterogeneities in aperture distributions and the deformability of the fracture affect the flow performance of the reservoir. The heterogeneous aperture enhances the flow channelling, which provides a high-permeability flow path between fracture boundaries and producer; hence, the average production rate is higher in heterogeneous cases, for the given input conditions, than that of the homogeneous ones. This circumstance is favourable in a case that a single fluid exists in the reservoir. However, if oil and water phases present in the system, this situation may lead to an early breakthrough of water. This study assumes an uncorrelated heterogeneous field; hence, further studies are required to capture and predict heterogeneity effect when the correlated heterogeneous field is introduced.

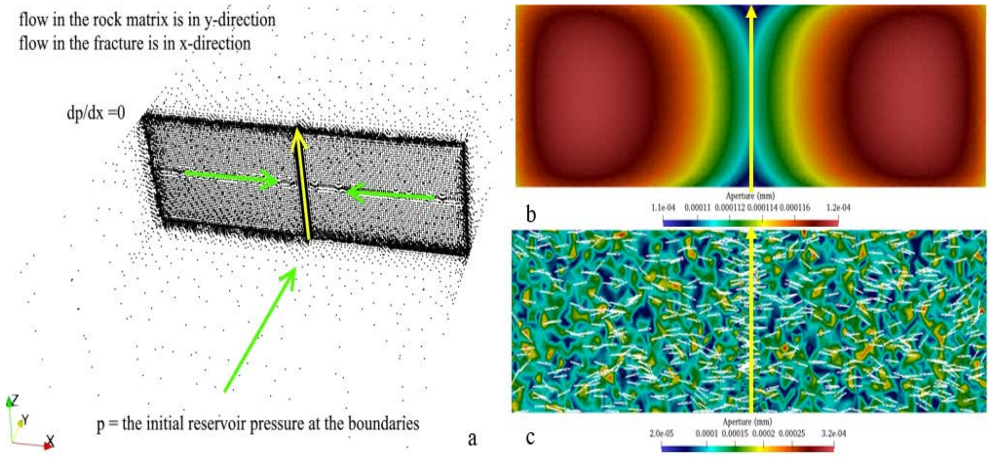


**Figure 1: a) model geometry b) homogeneous and c) heterogeneous deformable aperture**

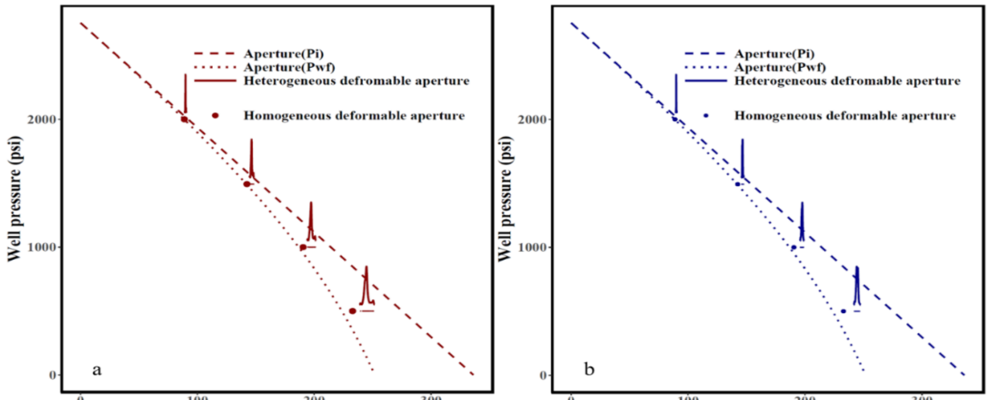


**Figure 2: Well pressure versus production rate: a) normal distribution, b) log-normal distribution**

## *References*

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