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Numerical simulation and geological modelling of conceptual fluvial reservoir systems.

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Numerical Simulation and Geological Modelling of Conceptual Fluvial Reservoir Systems

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Abstract— **the development of a fluvial reservoir oil or gas field poses complex challenges in field development strategies during appraisal and exploration stage due to some subsurface uncertainties. In this study, the channel geometries such as straight-channel, Y-shaped channel and U-shaped channel are assessed based on conceptual geological modelling. In order to provide robust information, a case scenario for both oil and gas fluvial producing reservoir are simulated using ECLIPSE 100- a black oil simulator, with data which has been adopted from Walsh and Gringarten [2]; Hogg et al. [6]. The result of the study shows that the pressure behaviour in the different channels is because of the change in channel geometry. This property determines the hydrocarbon recovery method and as such integration of analytical method, numerical simulation and geological modelling are employed as tools for planning field development strategies in fluvial reservoirs.**

Keywords—Fluvial reservoir systems, Fluvial channel geometry, Numerical simulation, Geological modelling.

I. INTRODUCTION

Fluvial reservoir systems are characterized as economically significant around the world due to the large amount of hydrocarbon reserves [1] and are mostly typical in the North Sea. It can be problematic and uncertain as fluvial deposits are usually influenced by several complex depositional elements, such as accommodation, topography of the field, and climate to forecast of high-quality and the distribution of large-volume reservoir facies [1]. Factors such as fluvial architecture (sinuosity and shape), spatial distribution (sand connectivity), the heterogeneity in petrophysical properties such porosity and permeability, and channel pattern which range from single storey channel bars to multi-storey and laterally interconnecting complexes causes great uncertainty during in a fluvial reservoir [2]. Channelized fluvial deposits representing channel fills, the aggradations of channel belts, or part or all the infill of valleys, form the major components of most fluvial reservoirs and aquifers, because they typically contain most of the potentially producible volumes. Therefore, the distributions of channel and over-bank deposits are tentatively reconstructed in workflows of subsurface characterization, a process aided by insight from outcrop studies of geologic analogues. However, the characterization of reservoir properties is difficult and subjected to large uncertainties [2]. Reservoir dynamic behavior can be predicted through geological modeling and numerical simulation identifying heterogeneity influencing fluid flow thereby evaluating the reservoir properties [3]. Numerical simulation is used to represent complex fluvial systems and can subsequently give more information when integrated in well testing. During the appraisal stage of an oilfield, several research to classify fluvial channels systems, points out the disparities in the different methodologies established and the interpretation of the data obtained through seismic survey have not assisted greatly with such classifications. The integration of dynamic geological models and numerical simulations can enable the forecasting of production to reduce the uncertainties associated with facilitating better field development cases.

The reservoirs found in fluvial environment are majorly classified into two main types: braided and meandering [4]. The braided reservoir is the most common in the fluvial depositional system. Realistically, channelized fluvial systems have complex networks of intersecting sand bodies which have different properties of permeabilities, porosities and net to gross ratios. This in turn leads to complex well testing behaviors [7].

The numerical simulation of pressure response test by designing different geological models with different ranges of heterogeneity among the multiple facies was conducted [8]. In the paper, data from well test of a long period of time was used to study low-energy multi-facies fluvial reservoir. Further analysis using an extended well-test programme showed that using the straight-line analysis the early time stage of the pressure derivative gives a skin factor of -1.9 and an effective permeability of 30 mD. This also indicated that the response from the derivative during build-up in the linear flow specialized regime commonly has a slope which is less than the log-log plot value of 0.5 [9]. It was concluded that the facies modeling had a major controlling effect in the simulated pressure transient response of the sand-shale reservoir.

Nugroho et al. [10] used analytical and numerical simulation to conduct transient well test reducing some subsurface uncertainties thus improving reservoir characterization. The paper provides workflow information for the application of pressure transient analysis to provide better insight on well deliverability in a deep-water gas condensate field. The PTA results provided useful insights to refine previous reservoir characterization in some critical areas such as: transmissibility *(kh)*, well deliverability, mechanical and rate-dependent skin, composite behavior, and reservoir boundary.

Franco et al. [11] proposed an approach based on the effect of different length of production with different rates in a single well-reservoir. The reservoir model simulated was tested by applying two methods; using the classic build-up test and simulation of different flowrates following period without shut-in periods to obtain the relevant data. It was concluded that the equivalent build-up test was similarly able to estimate the reservoir properties.

This paper presents the possibility of integrating different conceptual geological models and well testing data from numerical simulations for field development strategies associated with fluvial reservoir systems.

II. METHODOLOGY

A. Geological Modelling

Three geological models of Z-value 92m structures have been developed based on the conceptual understanding of different fluvial environment from a braided fluvial environment to a meandering fluvial environment using data from literature. The three geological models were designed with a grid dimension of 6950 m by 3950 m by 92 m (i.e., the dimension for x, y and z respectively) to give a rectangular grid. This was modeled using the PETREL software which allowed the heterogeneity of the averaging effect and the boundaries in the reservoir to be visible. The size of the grid cell is like the size of sand bodies found in Lower Sherwood sandstone of the Wytch Farm field [5]. The reservoir petrophysical properties used were also adopted from [6] which reported in the paper, the sandstone found in Sherwood formation is divided into two zones, a high net to gross fluvial at the base and a prevailing floodplain rock (mud) at the upper zone. The thicker sand-bodies at the lower part have an average porosity of 20% and permeability values which is usually greater than 1.5 Darcy.

The channel geometries were modeled as the reservoir facies in different fluvial environment with sand body dimensions of 105 m by 420 m by 2 m for the channel width, channel length and channel thickness, respectively. Shale background floodplain was used as the non-reservoir facies.

Table 1: Initial reservoir parameters used in the geological modelling

Parameters	Values
Initial reservoir pressure (P_i)	**3400 psia**
Horizontal Permeability (K_x)	**500 mD**
Vertical permeability (K_v)	**K_x* 0.1**
Reservoir Top Depth	**7400**
Porosity (Reservoir facies-sandstone)	**0.20**
Reservoir Temperature	**180°F**
Porosity (non-reservoir facies: shale)	**0.05**

B. Channel Geometries

The three models were created to represent different geometries to explore the effect on pressure responses. The geometric body dimensions for each model channel were adopted from [2]. The values are assumed to be the same for all the channels in the three conceptual models.

Table 2: Geometric body dimensions for channel geometries

Channel Geometry Content	
Channel Width (m)	105
Channel Thickness (m)	420
Channel Orientation (degrees)	270
Channel Amplitude (m)	0-750
Channel Wavelength (m)	1000

C. Conceptual Channel Models

To model the different types of concepts which were used for the numerical simulation and well testing, three channel geometries were used. The straight, U-shaped channel and Y-shaped channel which are shown in Fig. 1, Fig. 2, and Fig.3respectively.

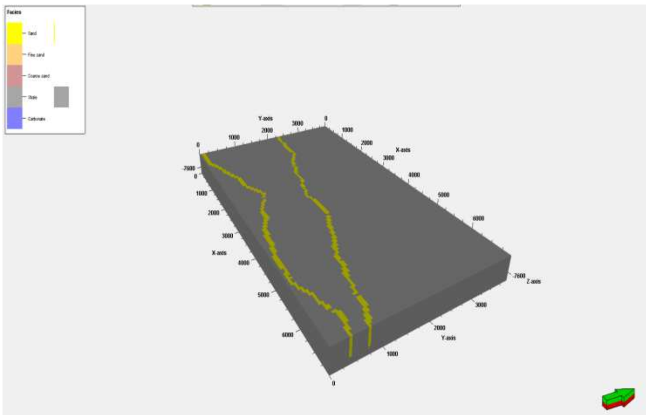

Figure 1: Object oriented diagram showing the facies in the straight channel geometry.

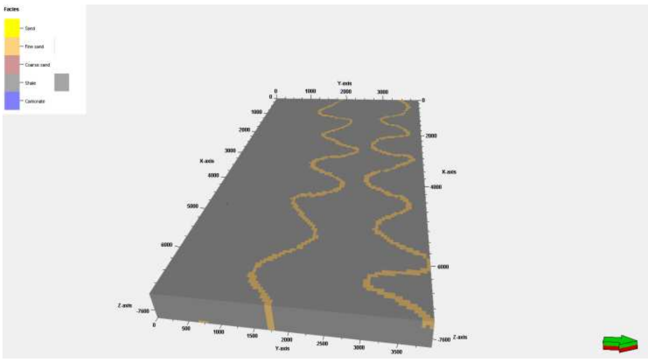

Figure 2: Object oriented diagram showing the facies in the U-channel geometry.

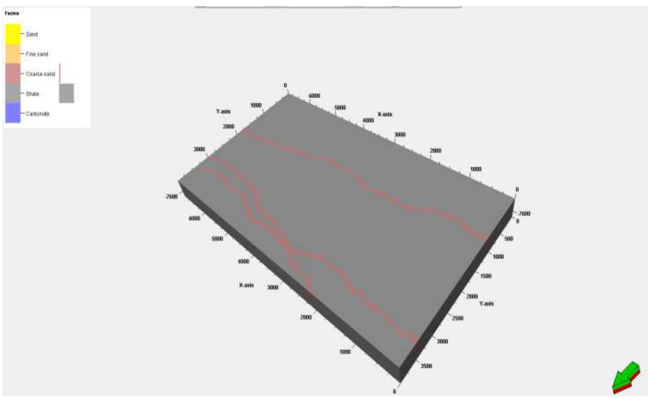

Figure 3: Object oriented diagram showing the facies in the Y-channel geometry.

D. Numerical Simulation of Production Data

The different properties for the sector model were exported to simulate the dynamic flow performance of the three conceptual channel geometries with 168x79x60 cells for evaluation of the well test response. An average grid size of 25x25x2ft in the direction of x, y and z respectively was used. The well-test data was modeled using Schlumberger's ECLIPSE reservoir simulator software for black oil. PVT data and petrophysical properties were obtained from the model specifications from PETREL. A vertical well was positioned in the channel which was completed through the entire reservoir interval.

The test history comprised of a short-term draw-down (12 hours in time steps of 30 seconds interval) with changing gas rates of 15000, 30000 and 45000 Mscf/day. An increase using logarithmic time steps was required to achieve this purpose which capture the pressure drop at the early time of the draw-down test (12 hours in time steps of 30 seconds interval) and the pressure build-up at early time for a duration of 24 hours with a high data frequency (taken in 1 second interval so as obtain the boundary effect in the well test analysis). Figure 4, 5 and 6 shows the bottomhole pressure and the established oil rate history for the three models.

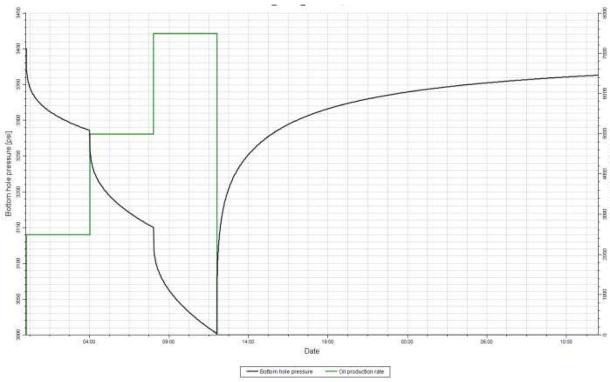

Figure 4: Pressure-oil rate history of the numerical simulation for straight channel geometry.

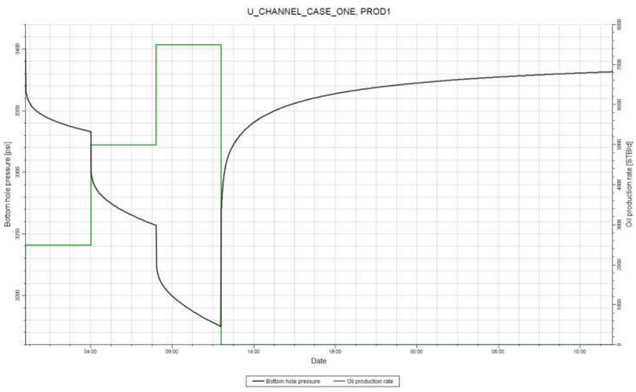

Figure 5: Pressure-oil rate history of the numerical simulation for U-channel geometry.

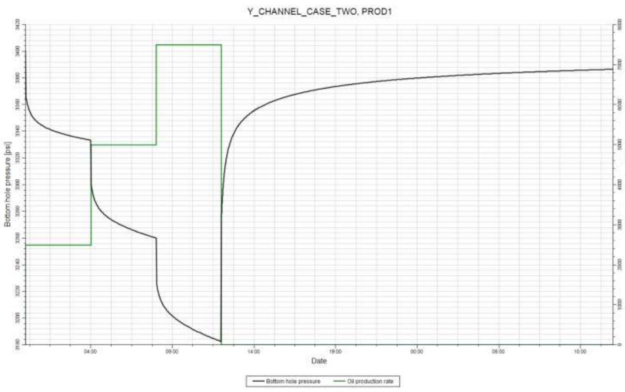

Figure 6: Pressure-oil rate history of the numerical simulation for Y-channel geometry.

III. Results and Discussion

1. Conceptual Modelling For The Fluvial Channel Geometries

Specific arithmetic value of permeability was assigned to both horizontal permeabilities (PermX and PermY) of 500 mD and 1000 mD respectively (**Fig. 7 and Fig. 8**) while the vertical permeability was set to value of 50md to provide a more robust information on the different channel geometries with respect to the simulation model scale. The distribution of the properties in the shale facies creates a form barrier to the pressure responses.

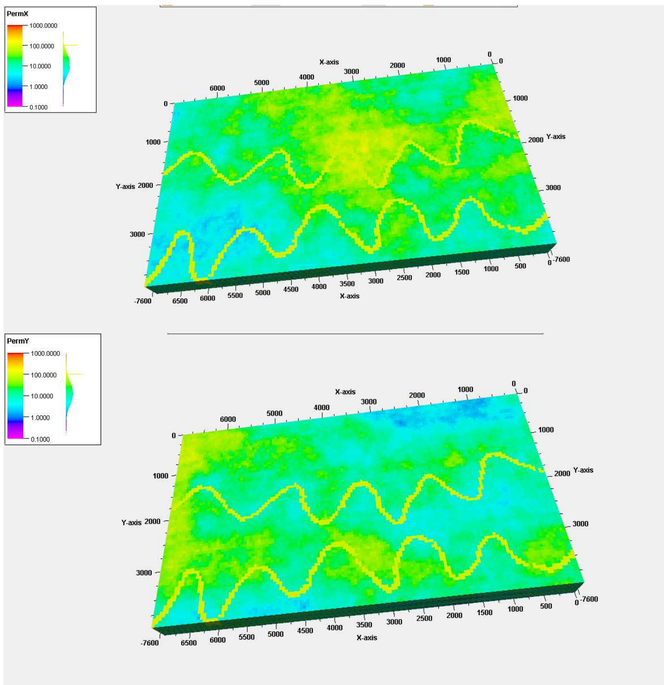

Figure 7: PermX (Top model) and PermY (Bottom model) for U-Shaped Channel Geometry

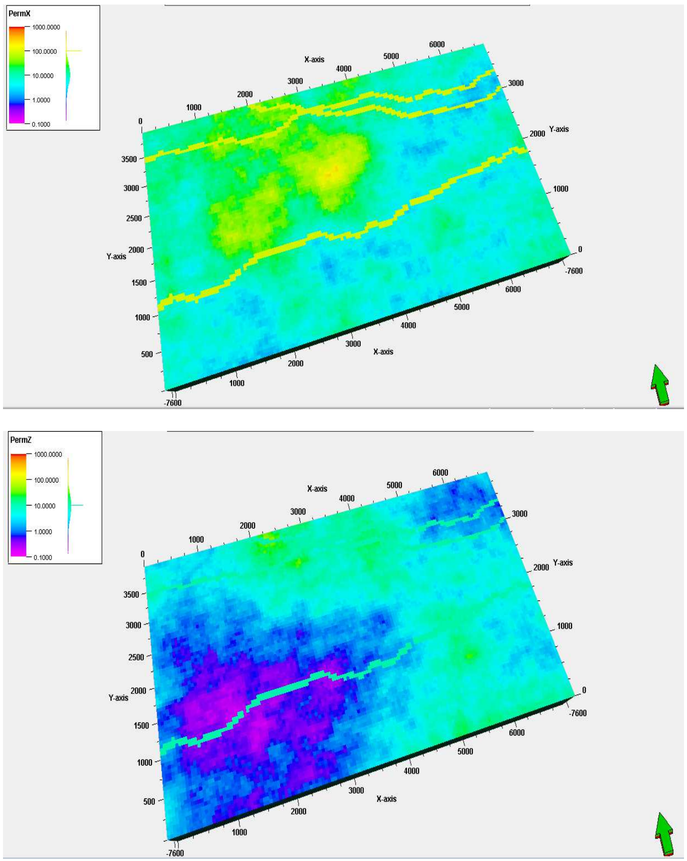

Figure 8: PermX (Top model) and PermY (Bottom model) for Y-Shaped Channel Geometry

2. WELL INTERPRETATION FROM NUMERICAL SIMULATION

The interpretation model to be used in this analysis is made up of the early time, middle time, and late time region. The early time region of the pressure transient is where the wellbore storage and skin factor are the most important. The radial flow is noticed in the middle time region while the boundaries can be seen in the late time region. This will be used to interpret the late transient boundary. The early time region of the pressure derivative curve in the analysis also shows an existence of a linear flow curve with a half-slope in the channel geometries as the channel boundaries are quite close to the wellbore. The linear flow trend is then interrupted by a small hump due to the pressure change due to the change in hydrostatic pressure reference. It will also be observed that the skin factor in the analytical model matching is negative due to the high permeability of the limited channel width. Based on the

IV. CONCLUSION

The data generated from numerical well test have been diagnosed using the ECLIPSE 100-a black oil simulator to determine different reservoir parameters. The well test pressure signatures can provide better insights about the heterogeneous nature of a fluvial reservoir system especially the main body (i.e., channels). The well test analysis has become a forgotten tool specifically for field development plan and locations of new development wells. From the results of this study, the following conclusions regarding simulation in different channel geometries for oil reservoir cases have been drawn:

1. Numerical Simulations that give a well test pressure signature was conducted for a conceptual case study of fluvial reservoir systems using a vertical well.
2. It is observed that complex reservoir modelling methods can be simplified into different reservoir features to provide better understanding into the area associated with uncertainties in fluvial reservoir systems.
3. The workflow adopted has been incorporated for oil scenarios in fluvial reservoir especially the main body (i.e., channels).
4. The heterogeneity of the reservoir is taken into consideration to establish further analysis in future work.

Implications of these findings for Industry

Fluvial reservoir systems are characterized as economically significant around the world due to the large amount of hydrocarbon reserves. The integration of dynamic conceptual geological models and numerical simulation can enable the forecasting of production to reduce the uncertainties associated with facilitating better field development cases.

Nomenclature

K_x= Horizontal Permeability
K_v= Vertical Permeability
C= Wellbore storage coefficient
K_e= Effective permeability
mD= milliDarcy
Kr_w= Water Relative Permeability

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