A Review on Pressure Transient Analysis in Multilayer Reservoir: South Iraq Case Study

Shamam T. Abdulkadhim¹,* and Dahlia A. Al-Obaidi¹

¹ Department of Petroleum Engineering, University of Baghdad, Baghdad, Iraq
* Correspondence: shamam.tarq92@gmail.com

Abstract

Multilayer reservoirs are currently modeled as a single zone system by averaging the reservoir parameters associated with each reservoir zone. However, this type of modeling is rarely accurate because a single zone system does not account for the fact that each zone's pressure decreases independently. Pressure drop for each zone has an effect on the total output and would result in inter-flow and the premature depletion of one of the zones. Understanding reservoir performance requires a precise estimation of each layer's permeability and skin factor. The Multilayer Transient Analysis is a well-testing technique designed to determine formation properties in more than one layer, and its effectiveness over the past two decades has been demonstrated. In order to conduct MTA, a combination of rate profiles derived from production data and transient rate and pressure measurements at multiple surface rates is necessary. Numerous experimental and analytic approaches to calculating multilayer characteristics, performance, and flow behavior in multilayer systems have emerged. This technology was implemented at the Zubair oil field in southern Iraq. In the last four years, the number of wells producing under saturation pressure has been increased in the Zubair oil field, particularly for the Mishrif and Zubair reservoirs. In the design of secondary and tertiary recovery, the study of the reservoir in the form of an individual layer to determine the pressure, permeability, and damage of each layer with commingled formation is important. This research describes previously available methods, factors that affect Multilayer Transient Analysis an economic indicator of Multilayer Transient Analysis and a case study

Keywords: Multilayer, Zubair oil field, Pressure, Skin, Permeability, South Iraq

1. Introduction

When multiple reservoir layers are produced simultaneously in the same well, regular Pressure Transient Analysis (PTA) methods fail to calculate the permeability and damage of individual reservoir layers. The normal pressure build-up test, in which the tool-gauges is usually positioned above the top of most perforations in the well, provides an average permeability measurement for the entire multilayered system (Moustafa et al., 2008). The Multi-Layer Transient Test (MTA) is used to determine the individual layer properties, such as permeability and skin, of multiple layers mixed in a well. Over the course of the past two decades, this strategy has proved to be effective. on the other hand, traditional MLT requires the utilization of rate profiles derived from production logs in addition to transient rate and pressure measurements obtained at numerous surface rates (Weibo, 2019).
Real reservoirs consist of strata or formations with varying thicknesses, permeabilities, porosities, and skin factors. In well testing terminology, these reservoir formations are referred to as multilayer systems. The behavior of pressure transient analysis for layered reservoirs has been divided into two types: commingled reservoirs with no cross flow between layers and multilayered reservoirs with cross flow between layers (Jiaen, 2014; Hussein, 2020).

Because stratified formations are the norm rather than the exception in oil and gas reservoirs (due to the heterogeneity the reservoir not uniform and consist from sub layers), it is crucial for development strategies, particularly secondary recovery, to comprise the properties of each individual layer (Yan and Michael, 2010). Log analysis is used as an essential resource for petroleum geologists to characterize the porosity, lithology, and geometry of the pores, in addition to permeability, which is frequently used to estimate oil reservoir levels (Buraq, 2021).

When the values and distribution of physical properties are known, it is straightforward to predict carbonate lithology, given the broad spectrum and sensitivity of measured parameters to lithological changes (Buraq, 2020). A correct estimation of rock and fluid components and the use of corrected records that discriminate between a combination of minerals and components will ensure the accuracy and dependability of the calculations (Ali and Ghanim, 2021). Carbonate rock reservoir properties are ordinary evaluated by means of logging, core analysis, and pressure transient analysis (Alobaidi, 2016; Adnan and Sameera, 2019). Multi-Layer Analysis (MTA) can obtain static and dynamic parameters from hundreds of meters to several kilometers range (Yongjie and Zhaobo, 2022; Francy et al., 2022).

Advances in computer processing power enabled the development of tools that can interpret not only a single build up or draw down, but also the entire pressure history acquired during a well test or the entire life of the well (when Permanent Down-Hole Gauges, PDHG, are available) utilizing either analytical solutions or numerical simulation techniques (Carlos et al., 2015; Adil et al., 2020). Even if the reservoir parameters have already been estimated, there are numerous benefits from conducting a type curve match. A type curve match utilizes the entire data set, whereas the semilog method and unit slope log-log line utilize only a subset. This ensures consistency over an extended period (Roland, 1995).

In reservoirs connected to an active aquifer or under water-flood conditions, producing wells are frequently initiated with a single-phase oil flow, followed by an increase in water cut once water penetrates these wells. For multiphase conditions, conventional Pressure Transient Analysis (PTA) procedures must be adapted. Moreover, in a multilayer environment, it is essential to differentiate between the effects of water in the affected layer and epidermis in other layers (Arashi et al., 2019; Al-Mudhafar et al., 2023; Al-Obaidi et al., 2023).

Various techniques are adopted throughout the well's life cycle in order to estimate representative formation parameters as shown in Table 1. Between these tests, the cased hole formation tester, the multilayer test, and Selective Inflow Performance (SIP) test are mostly used. Individual reservoirs are thoroughly evaluated due to the limitations of drill stem test and open hole log data (Asad et al., 2012).

By the effect of the natural reservoir depletion mechanism, oil wells begin to produce. At the time when the natural energy of the reservoir is vanished, artificial lift techniques are enforced. The most known of these artificial lift techniques are sucker rod pumps, gas lift, progressive cavity pumps, electric submersible pumps, and hydraulic jet pump (Mohammed et al, 2022). Artificial lift techniques are a highly effective solution to aid the deterioration of the production especially for mature oil fields. gas lift is one of the oldest and most applied artificial lift methods especially for large oil fields (Mohammed et al, 2021).
Table 1. Reservoir properties obtained from different transient test

<table>
<thead>
<tr>
<th>Types of Tests</th>
<th>Data Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill stem tests (DSTs)</td>
<td>Reservoir behavior, fluid samples, permeability, skin, fracture length, reservoir pressure and reservoir limit boundary</td>
</tr>
<tr>
<td>Wireline formation tests</td>
<td>Pressure profile, fluid samples and some reservoir properties</td>
</tr>
<tr>
<td>Drawdown tests (DD)</td>
<td>Reservoir behavior, permeability, skin, fracture length and reservoir limit boundary</td>
</tr>
<tr>
<td>Buildup tests (BU)</td>
<td>Reservoir behavior, permeability, skin, fracture length and reservoir pressure</td>
</tr>
<tr>
<td>Step-rate tests</td>
<td>Formation parting pressure, permeability and skin</td>
</tr>
<tr>
<td>Falloff tests</td>
<td>Mobility in various banks, skin, reservoir pressure, fracture length and location of front boundaries</td>
</tr>
<tr>
<td>Interference and pulse tests</td>
<td>Communication between wells, reservoir type behavior, porosity, interwall and vertical permeability</td>
</tr>
<tr>
<td>Multilayers reservoir tests</td>
<td>Properties of individual layers, horizontal and vertical permeability, skin, average layer pressure and outer boundaries</td>
</tr>
</tbody>
</table>

In certain instances, it may be advantageous in the oil field to restrict the flow rate at the surface in order to obtain liquid production with a lower gas-to-oil ratio. This can be accomplished by installing a surface constriction on the well head (Mohamed & Dheef, 2006). Currently, multilayer reservoirs are approximated as a single zone system by averaging reservoir properties corresponding to each reservoir zone. This method is simple for analyzing total production and wellhead pressure. This type of one-zone system modeling is rarely accurate because it does not take into consideration that each zone’s pressure declines independently. This decreasing in pressure for each zone has an effect on the overall production and would result in inter-flow and early depletion of one of the zones (Onwunyili et al., 2013).

In this research, the previous methods of Multilayer Pressure Transient Analysis (MTA) are discussed during different periods of time. Then some of wells in the Zubair oil field is taken as a case study. The Zubair oil field, depicted in Fig. 1, is located in southern Iraq and was found in 1947. It is one of Iraq’s most productive oilfields (Awos and Nada, 2020). It is located in southern Iraq, approximately 20 kilometers southwest of Basrah. It is situated between the latitudes of 47o 32' and 47o 45' and the longitudes of 30o 42' and 30o 05'. It covers an area of around 1170 km2. It is bounded in the north by the Nahran Umr Oilfield, in the west by the Rumaila Oilfield, and in the south by the Kuwait-Iraq border (Fig.1). From south to north, the Zubair Oil-field is made up of three domes: Safwan, Rafidiyah, and Shuaiba-Hammar (Aymen and Hussain, 2019; Mohand and Methaq, 2020).
2. Materials and Methods

Many studies of multilayered system behavior have been conducted since the early 1960s. With the introduction of production logging tools which measures bottom hole pressure and flow rate simultaneously in the 1980s, significant efforts have been made to quantitively interpret multilayered systems (Chengtai and Hedong, 2017). Three methods were used to survey the sections:

2.1. Numerical Methods

The application to PTA was specifically to constructed numerical models which was one of the important keys in the technical advances in recent years. Numerical models solve the major limits of the modeling methods. Most important feature is the ability to process complicate geometries, and solve a nonlinear diffusion problem for which the supper location in time and space of the analytical methods will not work (Olivier et al., 2018). Table 2. Shows a summary of multilayer test studies using numerical methods.
Table 2: Summary of Multi-Layer Test Studies Using Numerical Method

<table>
<thead>
<tr>
<th>Reference</th>
<th>Application, assumptions, accuracy, and limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(William et al., 1972)</strong></td>
<td>Pressure buildup for two layers, without crossflow systems has been thoroughly analyzed to determine the appropriate application of conventional analysis techniques. Using the single layer build up plotting forms proposed by Muskat, Miller-Dyes-Hutchinson, and Horner, it was determined that, under well-defined conditions, all three methods are applicable to two-layer systems. No crossflow system has been analyzed to ascertain the appropriate application of conventional analysis methods.</td>
</tr>
<tr>
<td><strong>(Elbel et al., 1990)</strong></td>
<td>Existing hydraulic fracture simulators do not adequately characterize the process of the extension of multiple fractures, which occurs in a substantial proportion of hydraulic fracture interventions carried out in formation and well completion settings that are conducive to this process. This reference described a technique for simulating multilayer fracture intervention simulations. The method utilized an analytical PKN fracture model to characterize the behavior of each fracture and couples behaviors using a set of constraints defining volume conservation and pressure continuity. Several examples are utilized to illustrate the simulator's effectiveness.</td>
</tr>
<tr>
<td><strong>(Shah and Spath, 1993)</strong></td>
<td>In commingled wells, layered reservoir tests (LRT) provide design and interpretation challenges when the layer potentials are independent, either at the beginning time or at the outer layer borders. To take into consideration different layer features and boundary conditions, multilayer models for commingled wells are created from existing single-layer analytical solutions. Some layers have a continuous pressure record at the outer edge, whereas others have no flow. With the help of the methods created here, reservoir engineers will be able to create and analyze multi-transient LRTs for the first time without the use of numerical simulation. This invention will not only significantly reduce the amount of computer time required, but it will also make it easier to comprehend tests carried out in reservoirs with geometries and characteristics that are more complex than those supported by current simulators. The outcomes of finite difference numerical simulation for three different reservoir systems was compared to test them and the effectiveness of the new approach was discussed. Calculating the total and individual stratum flow rates during a multi-transient test is necessary for the LRT interpretation given the observed wellbore potential during the test period and the well's production history. The suggested solution to this problem is based on a combination of fresh test design calculation techniques and tried-and-true flow rate calculation algorithms.</td>
</tr>
</tbody>
</table>
Large-scale reservoir heterogeneities, including fractures, faults, and strata can seriously impair the usefulness and efficacy of an IOR process. To help with the development of more efficient oil recovery techniques, it is essential to comprehend the level of connection between two wells that are physically separated by a fissure. Investigation of the interference pressure behavior of a multilayered damaged reservoir with both sealing and non-sealing flaws is under the purview of this reference work. A three-dimensional numerical model is used to predict and estimate the pressure responses at active wells and observation wells. To ascertain the effects of fault throw, formation transmissibility, and storativity on the interference pressure behavior, a sensitivity analysis is conducted. These types of curves are used to build a method for calculating the transmissibility of faults and formations as well as the formation storativity. For the system under examination, the dimensionless pressure type curves are first created and then assessed. The well test technique created as part of this project has the potential to be used for identifying reservoir features in order to include them in IOR simulations and optimizing field development plans for oil reservoir recovery by figuring out the best number and location of wells.

2.2. Analytical Methods

Since a long time ago, analytical solutions for the flow of a slightly-compressible, single phase, fluid layer have been visible. Many researchers have investigated the limiting conditions under which these methods can be applied to multilayer reservoirs with cross flow (Jackson et al., 2003). Table 3 shows a summary of Multi-Layer Transient Analysis using Analytical methods.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Application, assumptions, accuracy, and limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Robert et al.,1974)</td>
<td>Described the method for calculating the behavior of pressure accumulation in multilayer systems without crossflow. This method is applicable to infinite or closed systems with any number of wells and strata. The rate of production need not be constant.</td>
</tr>
<tr>
<td>(Raghavan et al.,1974)</td>
<td>It was regarded a two-layer horizontal and cylindrical reservoir with impermeable boundaries at the top, bottom, and exterior drainage radius. Each layer proposed to be homogeneous and filled with a fluid having a low compressibility and constant compressibility. In the reservoir, the pressure gradient is modest and the gravity impact is insignificant. The characteristics under consideration are the assumed layer porosity, permeability, and the thickness of the two zones.</td>
</tr>
</tbody>
</table>
In order to establish a method to predict the reservoir features of individual layers using transient well test data, an estimate of the unsteady flow in the infinite-acting period for multilayer reservoirs with and without interlayer crossflow was formulated. This estimate was constructed to compare multilayer reservoirs with and without interlayer crossflow. A conversation took place on the crossflow behavior brought on by the many different skin variables. A one-of-a-kind approach was used to determine the vertical permeabilities of low permeable shales as well as the diffusivity ratios between the different layers.

This paper summarized the methodologies that have been developed for evaluating multilayer reservoirs. Number of scientists have investigated the impact of layering on standard pressure transient testing.

When pressure varies, sealing faults that cut formations with or without contrasting rock characteristics alter the behavior of nearby well pressure. For wells remote from a fault, wellbore storage and skin effects are utilized to compare wellbore pressure with and without wellbore flow rate. In the absence of downhole flow rate, this analysis takes into account the constant wellbore storage and exponential decline flow rate models. The permeability, skin, and wellbore storage coefficient are determined using these advanced techniques. Determine how far the well fissure is. This reference exhibit solutions based on logarithmic convolution, deconvolution, and convolution as well as nonlinear least-squares estimation.

Two approaches for estimating the parameter value were proposed and evaluated, in which the initial and late time limiting values of the layer formation rates were combined with traditional pressure analysis for the overall system's average permeability and skin.

This work describes analytical approaches and procedures for analyzing transient testing of water injection wells in a multilayer oil reservoir with no crossflow. Saturation distributions are taken into account in the solutions. These responses show that pressure falloff data cannot be utilized to identify the characteristics of particular layers but rather frequently provide averaged waterflooding characteristics for a layered reservoir.

proposed a technique for determining what pressure changes in composite multilayer reservoirs with or without crossflow indicate. The suggested approach is valid for radial systems with an infinite, constant-pressure, or closed outer boundary. It also considers wellbore skins and storage effects. Flood fronts in the strata might be located at various distances from the well.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Pascal et al., 1992)</td>
<td>For the analysis of multi-layered tests, a solution procedure is presented. The foundation of this strategy is the analytical multiplication of a single-layer transient pressure response. Numerous possible inner and outer boundary conditions are possible, and cross-flow in the formation is taken into account.</td>
</tr>
<tr>
<td>(Edmond and Ambastha, 1993)</td>
<td>This reference established an entirely new analytical solution for multi-layered composite reservoirs with pseudo steady state interlayer crossflow. By comparing the findings of this analytical model to those of a few other straightforward, well-known models in the well testing literature, the findings were shown to be valid. There has also been discussion about the solution's technique and its potential applications in the future.</td>
</tr>
<tr>
<td>(Abbaszadeh et al., 1993)</td>
<td>Common analytical methods for pressure transient distribution in a multilayer reservoir with single and dual completion restricted-entry wells were reported. The solutions took anisotropic layers into consideration, as well as crossflow between layers.</td>
</tr>
<tr>
<td>(Sangsoo, 1994)</td>
<td>New correlation parameters were developed using analytical solutions to model multilayer reservoir solutions which produced during the boundary-dominated flow phase for multilayer reservoir stand rate production and compared them with a single-layer solution. These parameters can be used to model well responses for multilayer systems with equal or varying fracture lengths and border diameters, as well as single-layer systems with similar features.</td>
</tr>
<tr>
<td>(Chao et al., 1994)</td>
<td>Using an entirely new analytical simulator designed exclusively for multilayer reservoirs. This paper illustrates how, in contrast to a standard numerical simulator, an analytical simulator may be used to history-match field pressure records, production measurements, and anticipate reservoir performance.</td>
</tr>
</tbody>
</table>
This work sheds light on reservoir pressure responses when wells reach high-permeability layers. Depositional processes in different geological settings, such as fluvial and turbidite, generate major permeability differences. A published analytical multilayered composite-model calculates reservoir pressure response, including the high permeability lens. Pressure derivative curves show that the reaction starts of the same as the layered reservoir. As the pressure disturbance approaches the lens, the reaction changes flow phases. Lens features resemble stratified reservoirs, radial composite reservoirs, and horizontal hydraulically fractured reservoirs. Wellbore storage may conceal early flow cycles, making well test data analysis harder. Dimensionless variables and their sensitivity assist pressure-pressure derivative curve matching. Well production may be calculated. Field scenarios dictate reservoir lens size. The high-permeability lens reduces skin and promotes "enhanced" well formation.

It has been proved that reservoir characteristics for multilayered rectangular reservoirs with formation cross-flow may be derived using pressure and their semi-log derivative on a set of dimensionless type curves.

In a model of a single-well reservoir, the proposed method is predicated on the effect of two successive periods with distinct production rates. The well is initially operated at a constant rate until a quasi-steady state is attained. Then, the well is operated at a variable rate, resulting in a pressure transient response that can be measured at the wellbore's base.

In a vertical well with uniform flux in a multilayer reservoir with formation crossflow, pressure transient behavior has been observed. Analytical solutions are provided for the fundamental issue of pressure transient in multilayer reservoirs with any two neighboring layers crossflowing in the formation.

### 2.3 Mixed Analytical and Numerical Methods

In classic well test analysis, the analytical solution of the single-phase radial diffusivity equation with constant rock and fluid parameters is applied. Although analytical solutions for many reservoir and formation types have been developed, but without limitations. Reservoir simulator-based numerical models were developed to extend well testing and pressure transient analysis to multiphase flow difficulties, complex reservoir geometry and test configuration, and handling of mixed pressure and gradient barriers (Jackson et al., 2003).
Table 4. Summary of mixed numerical and analytical methods

<table>
<thead>
<tr>
<th>Author</th>
<th>Application, assumptions, accuracy, and limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Okoye et al., 1989)</td>
<td>This reference created a dual porosity system analytical model to analyze pressure transient data for wells intercepted by a finite-conductivity vertical fissure in a closed square multilayered reservoir. Wellbore storage affects the solution. Calculate fracture conductivity and half-length before comparing numerical and analytical solutions for two-layered and single-layered situations. Analytical asymptotic early, mid, and late-time solutions exist. Constant rate drawdown curves for transient pressure analysis were also created. Comparing drawdown and build up curves yields fracture half-length, reservoir permeability, and fracture conductivity. The type curve results showed that the approximated values of the aforementioned parameters match the sought parameter if the reservoir conductivity is known or can be derived from the data. This research solved a two-layered system and was applied to reservoirs with numbers of layers.</td>
</tr>
<tr>
<td>(Okoye et al., 1990)</td>
<td>Pressure transient data for wells intercepted by a finite-conductivity vertical fracture in a closed square multilayered reservoir are analyzed using a unique analytical model developed in this reference that makes use of the dual-porosity system idea. The solution takes into account wellbore storage. Before comparing numerical and analytical solutions, it is helpful to estimate the fracture half-length and fracture conductivity and then correlate multilayered (two-layered) and single-layer solutions. Also included are analytical answers for the earliest, intermediate, and latest possible times. In addition, constant rate drawdown curves were created to examine pressure changes over time. By comparing the drawdown and build up curves, the fracture half-length, reservoir permeability, and fracture conductivity were assessed. The findings of the type curve match favorable with the value of the target parameter if the reservoir conductivity is known or can be approximated from the available data. The findings of this research not only apply to reservoirs with numbers of layers, but also to those with just two.</td>
</tr>
<tr>
<td>(Jongkittinarukorn and Tiab, 1996)</td>
<td>This paper presented a boundary element method for solving the pressure transient of multilayer oil reservoirs. The proposed method can handle both Dirichlet and Neumann boundary conditions. The boundary element method has a number of benefits over the finite-differential and finite-element methods.</td>
</tr>
<tr>
<td>(Gomes and Reza, 1998)</td>
<td>The purpose of this reference is to develop a semi-analytical model for assessing pressure changes in stratified gas reservoirs. Layering, the high velocity effect, pressure-dependent gas characteristics, wellbore storage, and skin cause the flow problem in a gas reservoir.</td>
</tr>
<tr>
<td>(Nemcsok et al., 1998)</td>
<td>The integration of the static model, which included acquired 3D seismic data, with dynamic data allowed for an improved development plan that included both uncertainty and risk reduction. The dual-porosity system is used to examine pressure transient data for wells intercepted by a finite-conductivity vertical fissure in a closed square multilayered reservoir. An analytical solution is used to validate a numerical solution, and the solution consists of a single layer. There are also asymptotic analytical solutions at early, middle, and late times.</td>
</tr>
</tbody>
</table>
This paper presented new insights of pressure response of reservoirs in which the well intersects a high permeability lens. The lens is of a limited lateral extent and is embedded within a reservoir matrix. Such situations are observed to result from depositional processes in a variety of geological environments (e.g., fluvial and turbidite) where textural variations lead to large contrasts in permeability. A published analytical multi-layered composite model is adopted to calculate the pressure response of reservoirs including the high permeability lens. Close examination of pressure derivative curves reveals the response is identical to that of the layered reservoir at early times. However, once the pressure disturbance reaches the edge of the lens, the response shows characteristic flow periods. The response shows similarities to that of the layered reservoir, radial composite reservoir, or horizontal hydraulically fractured reservoir according to the lens properties. Wellbore storage may mask the flow periods in the early time period causing difficulties in the analysis of welltest data. Dimensionless variables are deduced, and sensitivities to those variables are investigated, which facilitates pressure–pressure derivative curve matching. The method to calculate a well productivity is presented. A field case is analyzed for estimating various reservoir properties (e.g., the size of the lens). This example illustrates that the high permeability lens reduces total skin and provides “enhanced” well productivity.

Research presented a semi-analytical model to obtain the pressure transient response for Vertical, horizontal or multilateral wells in heterogenous reservoirs. This model is based on the Green’s function solution of the three-dimensional pressure diffusivity equation for single phase flow in bounded and homogenous reservoir. Results from semi-analytical model are compared and validate against results obtained from both the finite difference and the finite element method. The model has also proven helpful in computing the pressure response for tight reservoirs with localized heterogeneity in the near wellbore region.
Within the scope of this study, crossflow is only allowed within the wellbore. Additionally, the generation, validation, and implementation of unique approximation (semi-analytical) solutions for the wellbore pressure and fractional flowrate responses of commingled layered reservoirs that do not have interlayer crossflow were investigated. The generation of multilayer solutions in the Laplace domain may be accomplished with these formulations by employing "basic" pressure drop relations for each layer as a strategy. Due to the fact that these fundamental relations were chosen, the formulation may be analytically inverted into the real domain. This technique offers a clear solution (although an approximate one) for multilayer reservoir systems. These two distinct pressure scenarios are what make up the "constant" and "linear" pressure examples that are a part of the fundamental relations. In addition to these techniques, we also present a formulation that we refer to as "Total Pressure/Rate Averaging" (TPRA) that may be used to determine the typical rate and pressure response for each stratum. However, due to the necessary mathematics, this approach can only be used in the case of a two-layer reservoir. Even though the "linear" pressure condition (non-zero intercept) results in the maximum performance, this method is restricted to using just two layers. The TPRA formulation, on the other hand, has the potential to be readily stretched to n-layers. The TPRA formulation is quite accurate; yet, in comparison to other available choices, it lacks precision.

Utilizing stable flow rate data from flow profiles tests acquired with production logging tools at the top of each layer prior to shutting in the well and conventional pressure build up or fall off data from the well to determine individual layer permeabilities, skin effect fractures half-length, and formation pressure for a well in commingled reservoirs.

This paper begins with a quantitative examination. Eclips 100 software was used to simulate the reservoir, and the production and pressure results were sent to Ecrin software for well test analysis. Different states of the analyzer were examined to determine the state with the smallest error, and recommendations were made to reduce the error, including the effect of regression point selection, beginning estimate, and layer production utilization.

Accurate simulation of hydraulic fracturing in naturally fractured reservoirs has a substantial influence on fracturing treatment process prediction. The goal of this research is to do a numerical analysis of the hydraulic fracturing processes in a multi-layered fractured reservoir. As a result, mechanical mass balance equations for fluids, solids, and their interactions with generated fractures were simultaneously solved using the finite element method in ABAQUS software. According to the findings of this study, increasing the depth of the layers from Layer A to Layer C increased the fluid leakage rate due to larger quantities of fluid loss at higher depths. By visualizing linear equations, it is possible to deduce that linear equations for other levels may be determined approximately without modeling all of the layers by deriving one linear equation for one layer. Furthermore, the maximum fracture opening pressures for Layers A-C are 60, 73, and 78 Mpa, respectively. It is inferred that greater pressure is required to develop or create new cracks in the formation at greater depths. By generating polynomial equations for each layer, on the other hand, it is argued that there is an approximate relationship for each layer, which may be enlarged for subsequent layers.
Furthermore, using this method, the pressure differential behavior can be predicted using the fracture propagation length without the need for any extra field application. As a result, the fracture opening profile for the deepest layer is roughly 9.5 because it has the best union between the fracture tips and the wellbore's center points. (Junior and Ozkan, 2021)

A semi-analytical model for estimating the pressure-transient response of vertical, horizontal, and multilateral wells in heterogeneous reservoirs was provided in this study. This model is based on the Green's function solution of the three-dimensional pressure diffusivity equation for single-phase flow in a limited and homogeneous reservoir, similar to the boundary element technique. To deal with reservoir heterogeneity, the reservoir is partitioned into homogeneous subsections and flow and pressure continuity is imposed at the interface of neighboring subsections. Using this semi-analytical model to compare and validate the findings of the finite differences and finite elements approaches.

2.4. Assumptions

- The reservoir thermal measurement remains constant, and the pore space is filled with a single-phase fluid of constant viscosity that is slightly compressible.
- The reservoir is made up of two layers that run parallel to each other and overlap. There are no flow restrictions where the two layers meet.
- The reservoir has uniform potential, and the two layers have the same initial pressure.
- Each layer is the same all the way through and has the same thickness. Each layer has the same permeability, porosity, and total compressibility.
- The reservoir is created with at constant flow rate.
- Gravitational force is insignificant. Mechanical skin factors are assumed to be zero and well storage effects are disregarded.

2.5. Factors that Influencing the Multilayers Reservoir Performance [Role of Well Testing]

- **Relative permeability:** if the relative permeability of all thin layers is the same, then the average water saturation will be higher in the less permeable layers than in the more permeable ones. This is because the less permeable layers have a lower ability to allow water to pass through them. Also, the layers that have lower permeabilities have a higher average pressure than the other layers.
- **Pore size:** If the pores in the less permeable layers are smaller than those in the more permeable layers, increased fluid flow resistance will be observed in the reservoir. Using the capillary pressure curves, this effect may be calculated.
- **Formation geometry:** The geometric shape and interlayer communication spatial distribution have significant effects on the exploitation of multilayer reservoirs.
- **Permeability anisotropy:** in most oil reservoirs, the vertical permeability is much lower than horizontal permeability.
- **N-layer systems:** the exploitation performance analysis is heavily reliant on the accuracy of flow equations, particularly in the case of the sum formulas.

2.6. The Economic Indicators of the Multilayer’s Reservoirs

- Shorter exploitation time.
- Higher oil recovery coefficient.
• Lower cost for the well perforation and completion.
• Shorter time for well interpretation information.

2.7. Case Study

Rock typing and reservoir characterization are significant tools in prediction and performance of reservoirs and in understanding reservoir architecture (Al-Jawad et al., 2020; Al-Dulaimy et al., 2021). The hydrocarbon storage capacity of a reservoir is determined by its porosity, but the deliverability is determined by its permeability (Ismail and Al-Najam, 2019).

The data recorded with two flowing periods and on shut-in. Well-X is vertical well, with total depth 2543m MD was drilled in 2016 and produced from reservoir Y which consists from two layers (layer A and layer B). Petrophysical interpretation has been done based on electrical logs recorded on Feb. 2016 as illustrated in Fig. 2.

• **Layer A** showed low porosity value with average +e value of (12.5%-10%) and SWE average of 15.7
• **Layer B** showed good porosity with average value of 20% and SWE average of 17.8%
• MTA uses a variety of parameters, including pressure and flow rate transients recorded with the production logging instrument in a stationary position as well as surveys of production log data. Pressure analysis in reservoir Y, Well-X was estimated through Static Gauge Survey (SGS), the tool stationed 10m above layer A, and job was performed in March 2022 as shown in Table 5.

Fig.2. Petrophysical Interpretation of Reservoir Y, Well-X
In this research, Saphir software is used, the fluid in the well is slightly compressible and linear with 7-inch casing size is covering the interval through reservoir Y. Interpreting these types of tests is complex because it is involving a large volume of data, and identification of reservoir model with large number of potentially unknown parameters. The input data are clarified in Table 6 through Table 4.

Table 6. PVT data for Well-X

<table>
<thead>
<tr>
<th>Zubair Field Reservoir</th>
<th>Mishrif Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation pressure (bubble point pressure) (psia)</td>
<td>1935</td>
</tr>
<tr>
<td>API°</td>
<td>26</td>
</tr>
<tr>
<td>Sg (g/cc) @ saturation pressure</td>
<td>0.8</td>
</tr>
<tr>
<td>Bo (Rb/STb)</td>
<td>1.31</td>
</tr>
<tr>
<td>oil viscosity (cp)</td>
<td>1.52</td>
</tr>
<tr>
<td>water salinity (ppm)</td>
<td>200000</td>
</tr>
</tbody>
</table>

Table 7. Well-X data

<table>
<thead>
<tr>
<th>well</th>
<th>Layer</th>
<th>Perforation depths RT (m)</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Top</td>
<td>Bottom</td>
</tr>
<tr>
<td>Well-1</td>
<td>A</td>
<td>2271</td>
<td>2278</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>2378</td>
<td>2382</td>
</tr>
<tr>
<td>Total</td>
<td>(m)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Job procedure was done as shown in Fig. 3:
3. Results

Table 8. And Table 9. show the output results from Saphir interpretation, for two layers.
Table 8. Model Parameters for Well-X

<table>
<thead>
<tr>
<th>Model Parameters</th>
<th>Layer A</th>
<th>Layer B</th>
</tr>
</thead>
<tbody>
<tr>
<td>skin</td>
<td>12.2</td>
<td>-2.33</td>
</tr>
<tr>
<td>Pi</td>
<td>2260 psia</td>
<td>2260 psia</td>
</tr>
<tr>
<td>k</td>
<td>117 md</td>
<td>45 md</td>
</tr>
<tr>
<td>h</td>
<td>23 ft</td>
<td>13.1 ft</td>
</tr>
<tr>
<td>phi</td>
<td>0.152</td>
<td>0.152</td>
</tr>
</tbody>
</table>

Table 9. Main Software Out Put for Well-X

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>porosity phi%</td>
<td>15.17</td>
</tr>
<tr>
<td>well Radius rw</td>
<td>0.354 ft</td>
</tr>
<tr>
<td>pay zone h</td>
<td>36.0892 ft</td>
</tr>
<tr>
<td>formation compressibility</td>
<td>3E-6psi-1</td>
</tr>
<tr>
<td>fluid type</td>
<td>Oil</td>
</tr>
</tbody>
</table>

**Selected Model**
- model option: multi-layer, commingled
- well: Vertical
- Reservoir: Homogeneous
- Boundary: Infinite

**Main Model Parameter**
- Tmatch: 23.9 hr-1
- Pmatch: 0.0129 psia-1
- C: 0.0405 bbl/psi
- Total skin: 9.62
- K.h total: 3280 md.ft
- K, average: 90.9 md

As comparison between the permeability calculated with open hole data and the permeability calculated with transient test, for layer A the value of k was close enough between both measurements. While layer B permeability curve from open hole data was not stable therefore the comparison couldn’t perform. Fig. 4 shows the permeability curve calculated with open hole data.
Pressure transient was recorded simultaneously with production data therefore it includes cuts, two draw down periods and one build up interval was recorded as shown in Fig. 5. Interpretation was based on Horner plot as shown in Fig. 6. In practice it is difficult to maintain a strictly constant flow rate during each flowing period, also the well was not shut-in before test for stabilization and that may effect on data quality which was not clear to detect Infinite Acting Radial Flow (IARF) as demonstrated in Fig. 7.

Log-log plot Fig. 7 exhibited the following characteristics:

- The maximum in the derivative is almost 1 log cycle or more above the horizontal portion of the derivative.
- The pressure-change curve is almost horizontal during IARF.
- The separation between the pressure-change curve and the pressure-derivative curve after the end of Well Bore Storage (WBS) is greater than 1½ log cycles.
- At the end of the WBS unit-slope line, the pressure-change and pressure-derivative curves separate at a point some distance above the horizontal portion of the derivative.
- The above features were indicating the presence of positive skin which was in an agreement with Well-X total skin.

For complex situation and noisy data where no specific behavior is noticed on the diagnostic plots, the linear plot of pressure and rates vs. time became the main tool.

Fig. 4. Calculated Permeability from Open Hole Data

Fig. 5. Well-X History Plot for Test Data
During IARF, a graph of pressure vs. time will form a straight line on a semi log scale. For semi log analysis of a drawdown test, the slope \( m \) of the semi log straight line gives the permeability and the intercept \( p_{1hr} \) gives the skin factor.

**Fig.7. Well-X Log-Log Plot**

4. Conclusions

Multilayer testing and analysis is an efficient method for estimating individual-layer permeabilities and skin factor from concurrently observed wellbore pressures and layer flow rates. Calculated permeability from open hole data can be utilized for a comparison with calculated permeability from transient data. The flowing phases should not be extended for so long that the boundaries are evident, as this could affect the processing of the data (will make the interpretation more complicate as the boundary condition will not be infinite and more data will be needed). Multilayer testing can be performed as a part of standard PLT survey (as pressure transient measurement and PLT passes can be recorded simultaneously). The analytical model that was used in this research does not include cross flow between layers in the reservoir (this property is related to Saphir software, in order to define cross flow between layers numerical model offer this property by defining vertical leakage governing the flow at the interference between each layer). However, cross flow between layers is permitted inside the well.
References


Bielenis, V., SPE, Faruk, C., the university of Oklahoma., 2013. Rigorous Simulation of Production from Commingled Multilayered Reservoirs under Various Crossflow and Boundary Conditions. Presented at SPE production and operations symposium held in Oklahoma.


Carlos, P., Yeo, C., Brunei Shell Petroleum., 2015. Integration of Pressure Transient Analysis in Reservoir Characterization: A Case Study. Society of Petroleum Engineers (SPE), Nusa Dua, Bali, Indonesia.

Chao, G., Jochen, J.E., Lee, W.J., 1994. Interpretation of Field Pressure and Production Data with a New Analytical Layered Reservoir Simulator. Society of Petroleum Engineers (SPE), Midland, Texas.


