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WELL TEST ANALYSIS OF TWO-LAYERED OIL RESERVOIR IN COMMINGLED FLOW SYSTEM

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Abstract

This paper presents multi-layer testing and analysis techniques to obtain layer permeabilities and skin factors using flow rate and transient pressure data which was generated into ECLIPSE100 simulation software. For the purpose of this study, we considered commingled reservoir and is defined as the joint production from two or more layers from a single common wellbore. For simplicity the commingling of two layers is considered, without measuring the individual flow rate from each layer, but measuring the combined flow rate from each layer. This study consists of two-layered radial reservoir model with single phase fluid, with measured reservoir and rock properties. The two-layered testing and analysis techniques are presentend and existing interpretation methods for estimating layer permeabilities; skin factors have been evaluated using the pressure transient data obtained from ECLIPSE100 simulation software.

The majority of the reservoirs which are found for exploitation as studied by different investigators suggest that they are exhibiting layering or stratification-a sequence of layers of different properties. The difference between their properties variation may range from high to low. These layers may have different formation properties porosity; permeability; thickness, skin factor and fluid characteristics and are commonly heterogeneous. The boundaries between these layers may usually have significant difference in properties from upper to the lower layer. Therefore the vertical sequence of the different layers may show permeability variations from good to poor. It is very important to identify the type and characteristic of layered reservoir because each layer has different influence on the primary and secondary recovery. There is always a complication of multiple layers testing, the possibility of different skin factors in different layers, the different depletion behaviour of layers with high or low initial pressures. As a reason, it becomes necessary to test multilayered system and analysis is more complex and the results become more ambiguous as compare to the single layer testing. For this reason simulation is a very important tool to minimize the ambiguity in multi-layered reservoir testing. By the simulation techniques different layers can be analysed on the basis of each layer contribution to the production during drawdown and build up.

Introduction

Layered reservoirs are composed of two or more layers that may have different formation properties porosity permeability thickness, skin factor and fluid characteristics and are commonly heterogeneous. These reservoir formations are called multilayered systems. Accurate determination of permeability, skin factor and pressure for each layer is necessary to understand the reservoir performance. There is a challenge of determining reservoir parameters in multilayered reservoirs, i.e. estimating layer permeabilities, skin factors and formation pressures from well test data.

The commingled system pressure response has been discussed by many authors, Lefkovits, et al (1961) was the first who presented his work on multilayered behaviour. After that in 1980s studies been focused on interpretation of parameters by measuring bottom hole pressure and rate with production logging tool. During these periods two models were introduced; ; the first one modeling the formation interlayers cross flow and and the second one modeling a flow barrier between the two formation layers. A comingled system in these layers communicates into the wellbore.

The first study concerning multilayered system with crossflow was done by Russell and Prats (1962). In the same year Katz and Tek presented his study on the beheaviour of crossflow system. In (1972) Cobb, et al looked at the well bore pressure response of two layered reservoir for many production and shut in conditions but his effort remained unsuccessful. Later on Raghavan, in (1974) worked on similar problem and was able to estimate individual layer properties in an effective way. Earlougher studied in (1974) the characteristics of pressure behaviour in build-up test for multilayered commingled system. Later in year (1978) Tariq and Ramey studied about the wellbore storage and skin factor of multilayered system.

Bourdet in (1985) solved the pressure response for a two layered reservoirs with crossflow with consideration of wellbore storage and skin factor. Ehlig-Economides since (1985) have contributed majorly in the study of well test analysis for multilayered reservoir system with formation crossflow. They investigated different analytical solution for multilayered system for the N layered crossflow with wellbore storage and skin and investigated early, late time behaviour of the each layer of reservoir rock. Ehlig-Economides and Joseph proposed a single transient testing procedure in multilayered reservoirs where the transient flow rates from all layers were monitored simultaneously. They interpreted the individual-layer flow contributions with the aid of an analytical solution of multilayer systems that could include formation crossflow. Their method is often not applicable in practice because of the inability of the currently available production monitoring equipment to satisfactorily measure the downhole flow rates simultaneously at multiple and arbitrary depth locations. Larsen (1989) proposed a method to determine flow capacity and skin factor into layered commingled system. In 1996 R.A Almehaideb presented his study on single well model to Drawdown and build-up analysis by using simulation model. In year 2000 R.R. Jackson and R.

Banerjee Schulmbereger attempted Multi-layer testing and analysis by use of numerical testing and simulation and disscused both field data and simulation data for analysis.

This work is intended to calculate the average reservoir properties as permeability and skin factor of two-layered reservoir in commingled flow sytem and analyse the depletion beheaviour to optimize the hydrocarbon recovery. A single well radial model with single phase fluid was considered with measured rock and fluid properties using ECLIPSE100 simulation software. The simulator was used to generate synthetic pressure transient data which was then interpreted into PanSystem well testing software. The impact of different rock properties and well test durations were considered.

Numerical Well Testing

In this study we have considered a single fully penetrated, vertical well in the centre of radial reservoir of two layers with initially uniform thickness h. The reservoir properties are assumed uniform and homogeneous. The fluid considered for this study is the single phase oil. The Black oil simulator was used to generate synthetic pressure transient data which was then interpreted into PanSystem well testing software. The reason for using synthetic data obtained from simulation was that the real well test data on two layered reservoir is usually of poor quality or it might be insufficient or of too short duration, and also there is possibility of a reservoir heterogeneities which may mislead the pressure transient response. In this study the simulated pressure behaviour was undertaken several controlled input parameters for analysis and build up of different cases for interpretation of characteristics of commingled system. The simulation model consisted of 40 ft thick perforated interval into two layers in a radial grid with an outer radius of 2000 ft. Careful modelling of near wellbore region was considered to accurately observe the pressure transient behaviour during well test. It means that not only fine grids are needed around the well but also very small time steps must be used in the intial hours of drawdown and build-Up periods. The model consists of 200 grid cells in radial direction, the nearest cell to the wellbore having a size of 0.32 ft with logarithmically increasing sizes from wellbore to the outer radius. In the same way we increased time steps logarithmically from beginning to the end of each drawdown and Build-Up periods, with simulation having 139 time steps. In this model we have neglected gravity and capillary effect. As this model consists of two layers initially having same properties and it also does not takes any effect of wellbore storage and mechanical skin. The reservoir has constant formation compressibility. The basic reservoir, fluid and formation properties are listed in following table 1.0.

Multi-Layer Transient Test Procedure

The pressure transient behaviour to be analysed (using Pansystem, ® EPS) was generated from (Black oil simulator ®Eclipse-100) as discussed in previous section of numerical well testing. In this case; we analysed only the Drawdown test for oil well. The radial model in the previous section indicates that the well penetrates two distinct sand formations which are separated by shale barrier and these sands communicate only at the wellbore. Interpretation of the structure raised concern that the reservoir areal extent might be of a small size and has closed boundary. Thus, two-layered system with possible limits on areal extent was believed to be the possible representation of the reservoir. The schedule of pressure build-Up and pressure Drawdown, which is kept constant in all the cases is given in table 2

Results and Discussions

The primary objective of this study was to analyse the two-layered reservoir behaviour in commingled flow system. In order to achieve this objective Eclipse-100 black oil simulation software was used to generate the pressure transient behaviour which is described in previous section of numerical well testing and then analysis was made by PanSystem software.

The base case and other representative cases for each scenario of the single phase two-layered reservoir was analysed and are now discussed in more detail. Fig.4.1 and fig-4.2 shows the log-log- and semi-log plots for Drawdown (DD) of the single phase case. This study was aimed initially to validate the simulation models built for this study. It can be seen that the analytical calculations from the diagnostic and specialized plots (gives the average permeability k(avg) =25 md, average skin S(avg) = -1.0, and initial Pressure of Pi = 3000 Psia). The Drawdown and build-Up periods were 3 and 34 days respectively. The model was then tested with other rock properties by varying input parameters such as permeability and skin values. The influence of pressure drop for one layer upon the other was studied and its impact on whole reservoir as combined layers was considered. For both layers the effect of depletion was observed after flowing the wells on low and high flow rates. Below is the discussion of different properties contrast and their effect upon commingled reservoir is discussed.

Case-1: Effect of Pressure Contrast (P1 = 4000 Psia) and (P2 = 3000Psia):

Case-1 shows the impact of layer pressure for drawdown due to change in pressure of layer 1 and layer 2. In this case the pressure for layer 2 was reduced to 3200 Psi, the rest of the parameters were same as in base model then transient behaviour was analysed the results are show in first case figures and tabulated below, which shows the well flows at the value of -2.33 skin, by which it can be interpreted that the well is stimulated. In this case the analytical results show no any change in other parameters from the base case scenario.

Case-2 Effect of Permeability ratio contrast (kv/kh = 1):

In this case, the effect of permeability change into different direction was analysed and the results are tabulated below. The radial permeability was kept constant for both layers as of 25 md, while the horizontal and vertical permeability were 100 md, respectively. As it is seen from the analysis results of the PanSystem software, case-2 figure shows the beheaviour in which the average value for the skin is 0.668, which shows the reservoir is damaged upto some extent.,whereas, initially it was considered as stimulated into PanSystem parameters. Due to high permeability values and high flow rate with low initial reservoir pressure, the layers reach the closed boundary as evidenced by a unit slope in the derivative, followed by a hump similar to the wellbore storage.

Eventually it can be observed that during the draw down period, if there is high perm and low pressure reservoir, the whole reservoir starts to deplete.

Case-3: Effect of skin contrast ($S_1 \neq S_2$)

Since multi-layered reservoirs are composed of rock with different characteristics, it is possible that they will be damaged differently as suggested by Archer, Hurst and Daltban; the objective of this section is to demonstrate the effects of different layers skin factors on the pressure response. For this purpose, we used skin value of -1.0 for layer one and 2.50 for layer two.

The impact of skin values was analysed by changing layer -1 skin with that of layer-2. The results are shown in figures of case-3. It is clear from figure that the skin factor has major impact on pressure and slope of the curve. It can be observed from log-log and radial flow plot, that the average skin factor of both the layerswith the given rate, flow capacity of the reservoir is the same as it was estimated from the base case.

Case-4: Effect of Porosity (Porosity = 0.25)

Porosity effect the storage capacity for the reservoir and if there is high value for porosity it can be seen there is high volume of initial in place and results are shown in figures of case-4. It was observed from the results of analytical solution that the well has skin factor value in negative which shows that it is stimulated.Due to high porosity and low pressure of the reservoir, it starts to deplete early.

Case-5: Effect of Permeability contrast ($K_1 \neq K_2$)

The effect of permeability contrast was seen by changing the reservoir permeability of theupper layer to 10 md and the lower layer to 500 md. Fast pressure drop was observed in the lower layer, whereas the pressure was maintained in the layer with very low permeability. The rapid decline in pressure drop was due to high permeability of that layer while the other layer was producing at a constant rate. Results of permeability and skin are presented into case-5, which shows the permeability anisotropy between two-layers.

Conclusion:

The integrated single well model was applied to the different cases of properties contrast to elaborate its utility for the well test interpretation in commingled layered reservoirs. The study enables the investigation of different issues related to pressure transient behaviour of two-layer commingled reservoirs. From the results obtained, following conclusions can be drawn:

- In the absence of wellbore storage effects, a short drawdown period ensures to achieve the radial flow regime.
- For the initial investigation, well was produced at a low rate, which shows no boundary effects. It suggests that it may take months or years for the boundary effect to be observed.
- For commingled system the reservoir boundary effects can be seen after changing some input parameters, such as increased flow rates andpermeability.
- The ability to simulate wellbore pressure and combined transient behaviour at each individual layer rates and thereby estimating average permeability of two-layers and average skin factor for both layers and then those results were matched by simulation with those into Eclipse-100 software for generating of pressure transient behaviour.
- There is ability to handle more complex situation of reservoir such as flow from high rate layer to low rate layer during Draw down in high pressure zones and low pressure zones.
- Depletion behaviour can be also observed for each individual layer and its effect upon the other layer.

Nomenclature

C_D = *Dimensionless storage co-efficient*

A = *Area,* ft^2

CA =*Dietz shape factor, dimensionless*

Ct =*Total system compressibility, psi-1*

Co =*Oil Compressibility, psi-1*

h =*Reservoir thickness, ft*

k = *Permeability, md in commingled system*

q_T = *total flow rate in a commingled system, STB/D*

t = *time, t, days*

K(avg) = *Average Permeability of two layers, md*

kh =*Transmissivity, md-ft*

*m** = *Slope of straight line on Pwf vs, t, psi/hr*

*p** = *Extrapolated value of Pws at infinite close-in time, psia*

P1 hr = *Pressure at t = 1 hr, straight line, psia*

PD (MBH) = *dimensionless MBH pressure*

Pi = *Initial pressure, psia*

Pavg, = *Average Reservoir Pressure, Psia*

Pwf = *Bottornhole flowing pressure, psia*

P' = *Derivative of Pressure, (Psi/hr)*
Qn = *Constant rate just before shut-in, bbl/day*
r_w =*Wellbore radius, ft*
re =*Drainage radius, ft*
$Rinv$, = *Radius of investigation, ft*
S = *Skin factor, dimensionless*
$S(avg)$ = *Average Skin dimensionless*
t_{DA} = *Dimensionless time*
$(t_{DA})_{pss}$ = *Dimensionless time*
tp, = *Equivalent flow time, hr*
$tpss$, = *Time at pseudo steady-state flow, hr*
Vp = *Reservoir drainage volume, STB*
ϕ = *Porosity, fractions*
μo = *Oil viscosity*
Bo =*Oil Formation Volume Factor*

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Table 1-ECLIPSE100 simulation input Parameters

Layer 1 Parameters			
Parameter	Symbol	Value	Unit
Permeability	K1	25	Md
Net pay	h1	20	Ft
Skin	S_1	-1.0	Dimensionless
Outer radius	re_1	2000	Ft
Porosity	Φ	10%	Percent
Total Compressibility	Ct_1	1.1E-06	1/Psi
Viscosity	μ	.993	cp

Layer 1 Parameters			
Parameter	Symbol	Value	Unit
Pressure	P1	3000	Psia
Wellbore radius	r_w	0.6	ft
Layer 2 Parameters			
Parameter	Symbol	Value	Unit
Pressure	P2	3000	Psia
Permeability	K2	25	md
Net pay	h2	20	ft
Skin	S2	-1.0	Dimensionless
Outer radius	r_{e2}	2000	ft
Porosity	Φ_2	10%	Percent
Total compressibility	Ct2	1.1E-06	1/Psi
Oil Viscosity	μ_2	1.00	cp

Production data

Parameter	Symbol	Value	Unit
Oil rate	Q_o	2000	STB/D
Gas rate	Q_g	0	MM.scf/D
Water rate	Q_w	0	BBL/D

Fluid Properties

Parameter	Symbol	Value	Unit
Oil viscosity	μ_o	1.25	cp
Gas oil ratio	GOR	0	Scf /BBL
Oil FVF	Bo	1.21	RB/STB
Gas FVF	B_g	0	Scf/STB
Oil compressibility	Co		1.1*10^-6/Psi

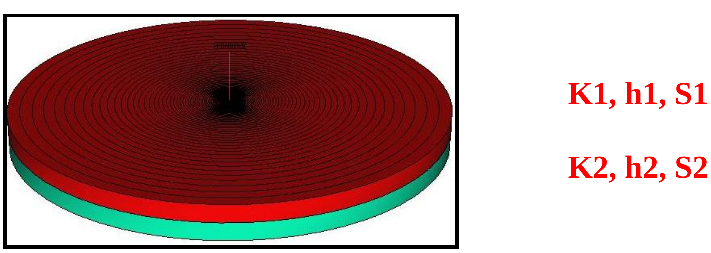


Fig. 1-Model for two-layered reservoir without cross flow

Fig-2. Combined Pressure Transient Beheaviour of two-layered reservoir

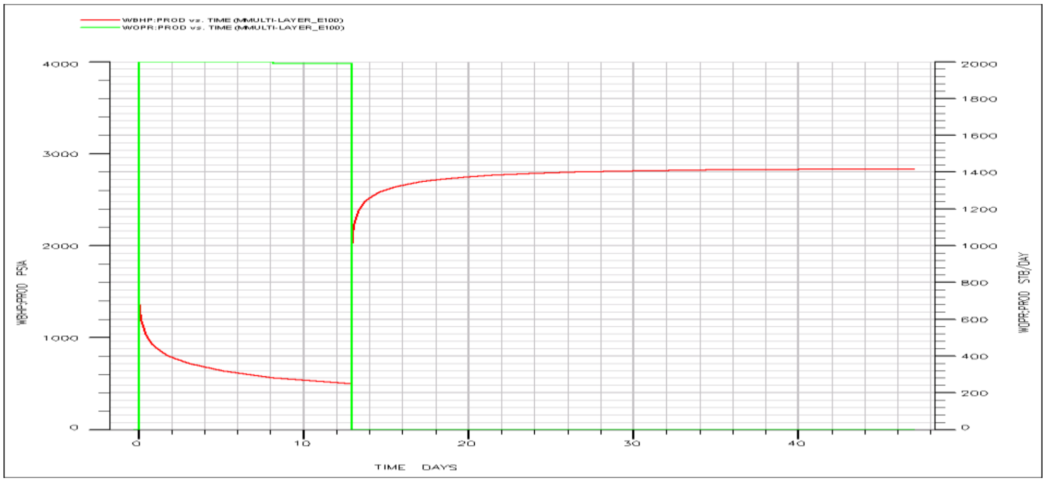


Table-2: Test schedule

Test	Test Duration (Days)	Flow rate (STB/Day)
Build Up	34	0.00
Drawdown	13	2000

Fig.3-Log-log Plot

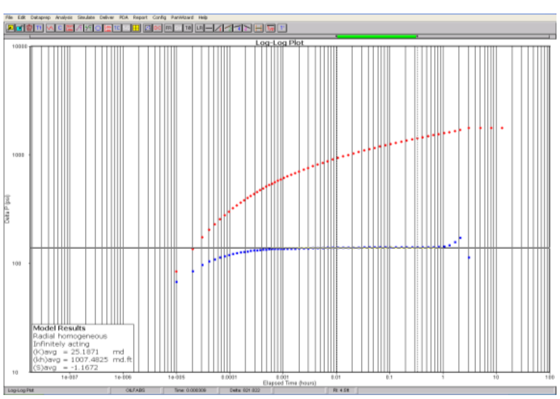
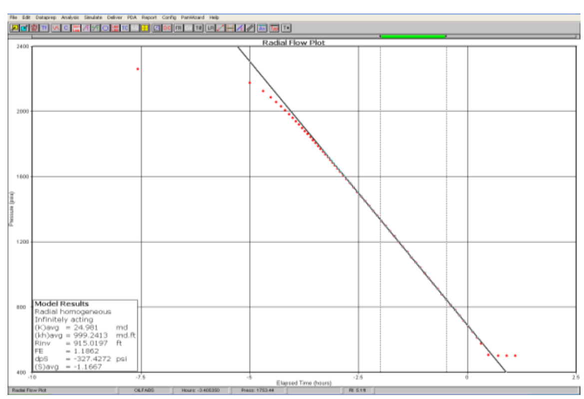
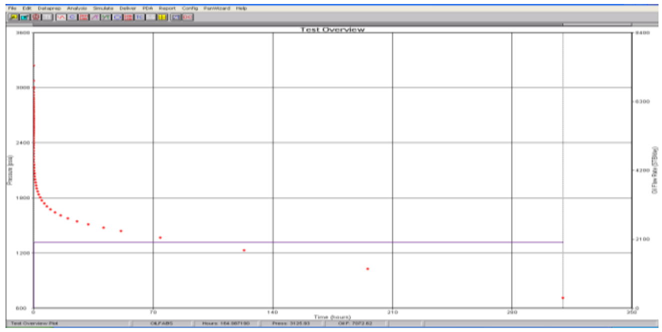
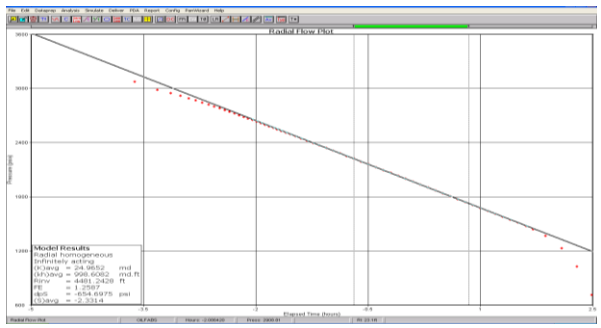


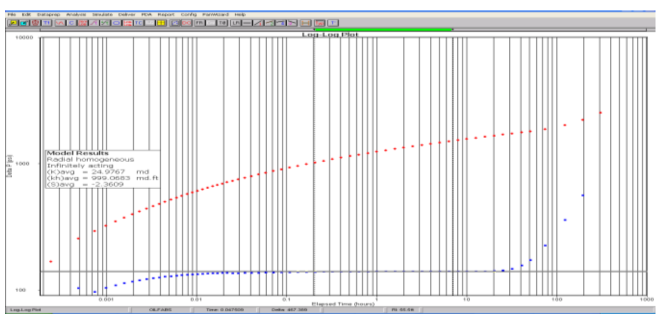
Fig.4-Semi-log Plot



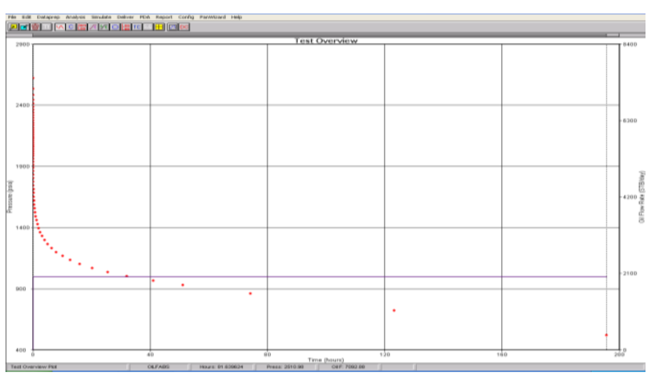
Case-1: Effect of Pressure P1=4000 Psia and P2= 3200 Psia upon commingled Reservoir

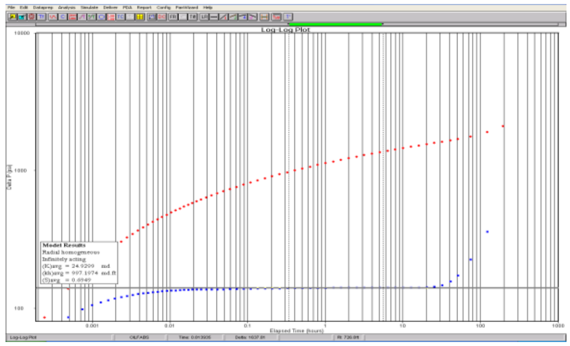


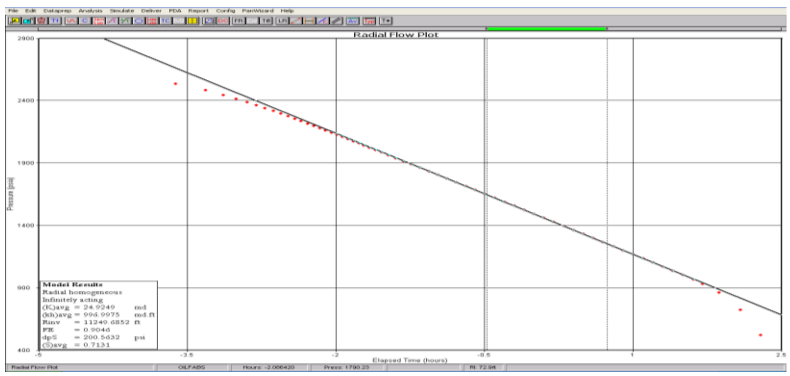




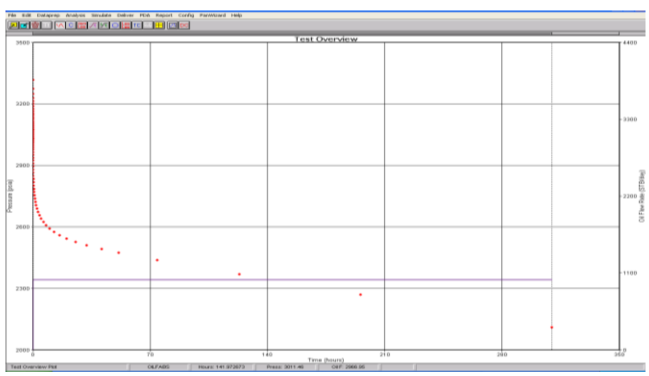
Case-2 Effect of Kh /Kv=1 upon commingled Reservoir

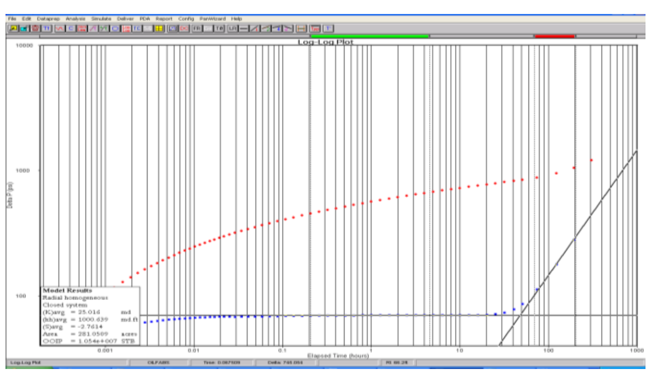


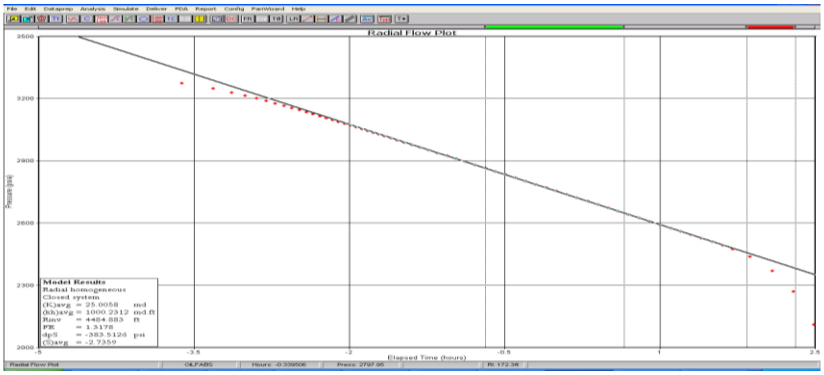




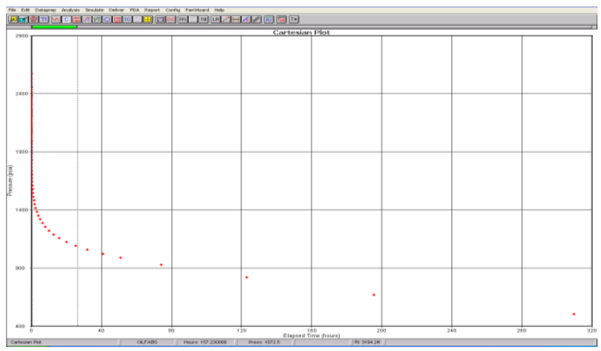
Case-3 Effect of Skin S1=-1.0 and S=2.5

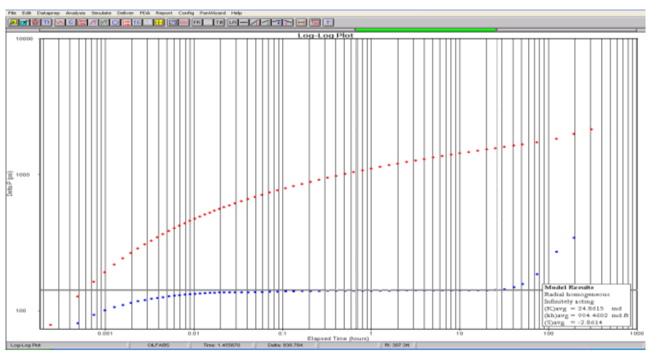


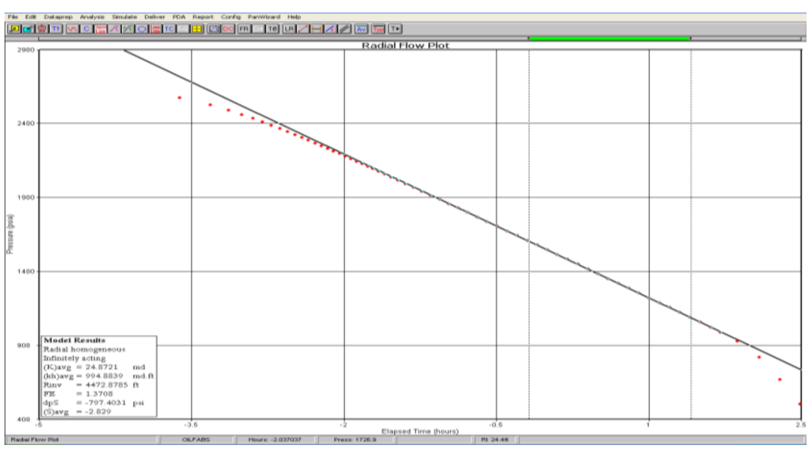




Case-4 Effect of Porosity 12% and 25 % upon commingled Reservoir







Case-5 Effect of Permeability contrast ($K_1 \neq K_2$)