Pressure Data Analysis and Multilayer Modeling of a Gas-Condansate Reservoir

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ABSTRACT

Kailastila gas field located at Golapgonj, Sylhet is one of the largest gas fields in Bangladesh. It produces a high amount of condensate along with natural gas. For the high values of GOR, it may be treated as a wet gas at reservoir condition. Three main sand reservoirs are confirmed in this field (upper, middle & lower).In this study, it has been shown that reservoir parameters of this gas field can be obtained for multilayered rectangular reservoir with formation cross-flow using pressure and their semi log derivative on a set of dimensionless type curve.The effects of the reservoir parameters such as permeability, skin, storage coefficient, and others such as reservoir areal extent and layering on the wellbore response, pressure are investigated.Shut in pressures are used in calculating permeability, skin factor, average reservoir pressure, wellbore storage effect and other reservoir properties. The direction of the formation cross flow is determined, first by the layer permeability and later by the skin factor.Finally, it is recommended to perform diagnostic analysis along with multilayer modeling to extract better results.Reservoir can also be considered as a multilayer cylindrical and can also use these models for other fields.

Keywords: Pressure derivative analysis, skin factor, wellbore storage, permeability, multilayer

Source of Support: Nil
Conflict of Interest: **Non d**eclared

INTRODUCTION

Kailastila gas field is one of the largest gas producing fields in Bangladesh. The objectives of this study are to estimate reservoir properties by performing diagnostic analysis and to create multilayer model of Kailastila gas field.

A common practice for development of multilayer gas and gas condensate fields involves wells producing commingled fluids from several formations that comprise one production target. For example, in West Siberia, multilayer fields producing from two or five or more formations are included in the commingled production zone. Although this practice can be economical in that it decreases the number of wells per field, simultaneous production from several formations similar reservoir properties (thickness, permeability, porosity and initial gas saturation), in many cases it is necessary to include a formation with considerably different thickness and permeability values. Such a variance in reservoir properties can lead to uneven damage and rapid depletion of more permeable formations. In this case, a well shutdown is accomplished by gas cross flow between formations (Shandrygin *etl*, 2010).

In this study multilayer modeling is created for three layers by using Bourdet model. The direction of the formation cross flow is determined, first by the layer permeability and later by the skin factor.Well test data has often been interpreted based on an assumption that the reservoir is a homogeneous single layer. However, many reservoirs are found to be composed of a number of layers whose characteristics are different from each other. Wells in such reservoirs may produce from more than one layer (Bourdet *etl*, 1989). This kind of pressure behavior which indicates vertically heterogeneous system is not necessarily like that of a single layered system, and seldom reveals more than the average properties of the entire system. To identify the characteristics of the individual layers is important to extract better results.

GAS PRODUCTION FROM MULTILAYER RESERVOIR

MODEL ASSUMPTION

Modeling is the process of history matching of pressure transient data based on a mathematical model. It is important to analyze the pressure transient data before modeling because it forces the analyst to think about the probable reservoir configurations and provides good estimates of reservoir parameters (Fekete, 2009). Multilayer modeling, a tool based on theoretical background, simulates the pressure responses in a multilayered well within a rectangular shaped reservoir with homogeneous characteristics in individual layer.

The model used here to describe multi-layer reservoir was developed by D. Bourdet. It is based on the following assumptions:

-The fluids flow horizontally each layer.

-The vertical flow between the three layers is instantaneously pseudo-steady state.

MODEL DESCRIPTION

Two different multilayered reservoir models have been proposed, depending on the presence or absence of interlayer cross flow. A multilayered reservoir is called a cross flow system if fluid can move between layers and a commingled system if layers communicate only through the wellbore.In this study, commingled system is used. This model simulates the transient flow in any number of independent layers commingled at the wellbore. Each layer is considered to have a rectangular geometry with an identical initial pressure (p_i) to other layers as well as its own skin factor, reservoir properties, and outer boundary condition (Perk, 1989).

The reservoir with multi layers is characterized by its:

-net thickness

-porosity

-saturation
-pore compressibility
-horizontal permeability
-vertical permeability
-skin

The main parameters that are involved in this model are:
-Total reservoir transmissivity
$kh = k_1h_1 + k_2h_2 + k_3h_3$
-The skin of each layer: S_1, S_2, S_3
-Total reservoir capacity, φc_t
-Capacity contrast between three layers, ω (Bourdet *etl*, 1989).

In this study, It is attempted to match the semi log curve mainly, then derivative type curve and dimensionless type curve to get a good model match with reservoir parameters but it does not attempted to match the wellbore storage regime because the buildup shows some transients occurring while the was shut-in and the wellbore storage effect could not be captured analytically analysis.

Pressure Derivative Analysis with Multilayer Modeling

Several methods can be considered in testing a multilayer model. They do not all allow the individual characteristics of each layer to be determined. Each layer has been tested separately.

The values of parameter obtained during the analysis step provide a good starting point for an appropriately chosen model type. Parameters can then be optimized by automatic parameter estimation (APE). Before using the APE method, corrupted data should be removed from the data set to prevent the attempted match from invalid points (Fekete, 2009).

The pressure build-up test, type curve analysis, Dietz_MBH method and multilayer modeling are used to complete this study. Permeability and skin due to damage are estimated by build-up test of radial analysis by developing semi log and derivative type curves. These values of parameters are used as input parameters for Dietz_MBH method. The Dietz_MBH method gives the output values of reservoir areal extents and these areal extents again used as input parameters for Dietz_MBH method and finally the average reservoir pressure is estimated..Multilayer modeling is created by adding three layers. The properties of these three layers such as permeability, thickness, compressibility, viscosity, and capacity contrast ω and exchange term λ are inserted. Then multilayer model is created.

Figure 1, 2, 3, 4, 5 and Figure 6 illustrates the multilayer model analysis results for the KTL-01, KTL-02 & KTL-04 in graphical form. From Figure- 1, 3 &5 it is seen that the modeled pressure line well matched with reservoir original pressure data points except slight deviation in the tail portion. Figure 2, 4 & 6 of derivative type curves shows all three pressures, pressure derivative and dimensionless pressure derivative model curves near closely fitted with corresponding reservoir data points.

Influence of Reservoir Properties on Production

In this section I presented a brief discussion on parameters obtained from diagnostic analysis, vertical model analysis, and multilayer model analysis. From table 4, it is obtained that the total skin effect ($\acute{S}$) is negative for well KTL-01.For well KTL-02, total

skin effect is positive. Total skin effect for well KTL-04 is positive and greater than KTL-02.These total negative skin indicates the well can be either stimulated or damaged. Because all the skin components that contribute to the total skin are always non-negative (i.e. are zero or positive) except for skin due to damage (S_d). The positive skin for KTL-02 and KTL-04 cannot give us clear information that it is damaged because the skin components have not been analyzed.
The average reservoir pressure, P_{avg} (3501.1.psia) for KTL-01 and P_{avg}(3489.7) for KTL-04 from Dietz_MBH analysis in Table 7.1 and Table 7.3 are closer to initial reservoir pressure indicate that the reservoir is at its early stage of production. In case of KTL-02 the average reservoir pressure is greater than the initial reservoir pressure. This is due to either for error in data recording during test.
The areal extents show the reservoir is rectangular in shape which is consistent with assumption.
The estimated parameters are tabulated here from pressure semi log plots, pressure derivative type curve and dimensionless type curve. The resultant values of a specific parameter obtained from all analysis methods are same so they are not repeated.
Extrapolated pressure, P^*= 3503.3 psia for KTL-01, P^*= 3222.1 psia for KTL-02 and P^*= 3489.7 for KTL-04 are found for final shut in pressure 3499.29 psia,3221.1 psia and 3488.9 respectively.
A multilayered system with formation cross flow responds to the production in three progressive stages. It behaves like a commingled system at early time and like an equivalent homogeneous system at late time (the semi-log straight line in the pressure curve). Transition occurs in the intermediate stage. The direction of the cross flow is governed first by the permeability and next by the skin factors. The cross flow starts from the less permeable layer to the more permeable layer in the beginning and from the layer with greater skin to the layer with smaller skin later (Perk, 1989).
From multilayer modeling, it is obtained that the permeability of layer 1 is greater than layer 2 and the permeability of layer 2 is greater than layer 3 for KTL-01, KTL-02 and KTL-04 .On the other hand the skin effect of layer 1 is smaller than layer 2 and layer 2 is smaller than layer 3.So the cross flow starts from layer 3 to layer 1 through layer 2.This time it behaves like a commingled system (Al-Mansoori, 2007).
Damage ratio refers that pressure drop due to skin is high. Recovery technique should be taken.
Flow efficiency indicates that the reservoir has fair flow capacity.

CONCLUSION

A multilayered system with formation cross flow responds to the production in three progressive stages. It behaves like a commingled system at early time and like an equivalent homogeneous system at late time (the semi log straight line in the pressure curve). Transition occurs in the intermediate stage.The direction of the cross flow is governed first by the permeability's and next by the skin factors. The cross flow starts from the less permeable layer to the more permeable layer in the beginning and from the layer with greater skin to the layer with smaller skin later.From this study, it is obtained that the permeability of layer 1 is greater than layer 2 and the permeability of layer 2 is greater than layer 3 for KTL-01, KTL-02 and KTL-04. On the other hand the skin effect of layer 1 is smaller than layer 2 and layer 2 is smaller than layer 3.So the cross flow starts from layer 3 to layer 1 through layer 2. This time it behaves like a commingled system.According to the diagnostic analysis results, it is sighted that the analysis value of permeability of KTL-01, KTL-02 & KTL-04 are 47.5327 md, 690.8167 md, 283.1997 md. It is clear that Kailastila is a good reservoir and have good permeability as well as good flow capacity. Finally, Multilayer modeling can be a good tool to estimate reservoir properties as it is not possible to acquire the whole reservoir characteristics by investigating only one layer. But if multilayer layer modeling is performed it is easy to characterize the whole reservoir.

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NOMENCLATURE

k = Permeability (mD)

ϕ= Total porosity (fraction)

S = skin

q_g = Gas rate (MMscf / d)

Pi = Initial reservoir pressure (psia)

$Pi_{(syn)}$= Synthetic initial reservoir pressure (psia)

P^* = Extrapolated pressure (psia)

p_R=Averagereservoir pressure (psia)

p_b = Base pressure (14.696psia)

Δp_{skin} = Pressure drop due to skin (psia)

Pw= Wellbore pressure (psia)

p_{wD} = Dimensionless wellbore pressure

p_{wf} = Flowing pressure (psia)

p_{wfo} =Final flowing pressure(psia)

p_{ws} = Shut-in pressure (psia)

$\Psi=P_p$ Pseudo-pressure (psi^2/cp)

$\Psi^* = P_p^*$ =Extrapolated pseudo-pressure (psi^2/cp)

$\Delta\Psi=\Delta Pp$=Delta pseudo-pressure (psi^2/cp)

$\psi_{ws}=P_{ws}$= Shut-in pseudo-pressure (psi^2/cp)

$\Psi_{ws}^* = P_p^*$ =Extrapolated shut-in pseudo-pressure (psi^2 /cp)

A =Drainage area (ft^2)

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Table 1: General input parameters for KTL-01. All values are taken from the report of AL MANSOORI Wireline Services.

General Input Parameter		
Parameters	**Values**	**Remarks**
Well Radius (inches)	4	Provided by Client
Net Drained Thickness (ft)	65	Interval tested: 9652′-9655′, 9658′-9664′, 9668′-9722′
Effective Porosity (%)	0.16	Assumed value
Gas Gravity	0.59	Reported value during the test
Primary Separator Pressure (Psia)	1000	
Primary Separator Temp ('F)	70	
CO2 Component (mol %)	0.142	Provided by Client
H2S Component (mol %)	Nill	Provided by Client
N2 Component (mol %)	N/A	Provided by Client
Water Salinity (ppm)	10000	Assumed value
Initial Reservoir Pressure (Psia)	3515	From the PTA
Initial Reservoir Temp ('F)	166.3	From the Temperature Gauge
Rock Compressibility (psi-1)	N/A	Not relevant
Gas Saturation(%)	64	Provided by Client
Gas Viscosity(μ_g)	0.0196	Calculated value
Gas compressibility factor(z)	0.856	Calculated value
Connate water saturation (%)	36	Provided by Client

Table 2: General input parameters for KTL-02.All values are taken from the report of AL MANSOORI Wire line Services.

General Input Parameters		
Parameters	**Values**	**Remarks**
Well Radius (inches)	3.5	Provided by Client
Net Drained Thickness (ft)	40	Interval tested: 7390′-7430′
Effective Porosity (%)	0.16	Assumed value
Gas Gravity	0.586	Reported value during the test
Primary Separator Pressure (Psia)	1000	
Primary Separator Temp ('F)	70	
CO2 Component (mol %)	0.139	Provided by Client
H2S Component (mol %)	Nill	This value is not available
N2 Component (mol %)	N/A	This value is not available
Water Salinity (ppm)	10000	Assumed value
Initial Reservoir Pressure (Psia)	3221	From the PTA
Initial Reservoir Temp ('F)	145.11	From the Temperature Gauge
Rock Compressibility (psi-1)	N/A	Not relevant
Gas Saturation	85	Provided by Client.
Gas Viscosity(μ_g)	0.0192	Calculated Value
Gas compressibility factor(z)	0.884	Calculated Value
Connate water saturation (%)	15	Provided by Client.

Table 3: General input parameters for KTL-04.All values are taken from the report of AL MANSOORI Wire line Services.

General Input Parameters		
Parameters	**Values**	**Remarks**
Well Radius (inches)	3.5	Provided by Client
Net Drained Thickness (ft)	69	Interval tested: 9610′-9673′ and 9696′-9702′
Effective Porosity (%)	0.1	Assumed value
Gas Gravity	0.586	Reported value during the test
Primary Separator Pressure (Psia)	1000	
Primary Separator Temp (‘F)	70	
CO_2 Component (mol %)	0.1432	Provided by client
H_2S Component (mol %)	Nill	This value is not available
N_2 Component (mol %)	N/A	This value is not available
Water Salinity (ppm)	10000	Assumed value
Initial Reservoir Pressure (Psia)	3491	From the PTA
Initial Reservoir Temp (‘F)	162.7	From the Temperature Gauge
Rock Compressibility (psi^{-1})	N/A	Not relevant
Gas Saturation (%)	64	Provided by client
Gas Viscosity(μ_g)	0.0198	Calculated Value
Gas compressibility factor(z)	0.911	Calculated Value
Connate water saturation (%)	36	Provided by client

Table 4: Multilayer model analysis value for KTL-01, KTL-02 & KTL-04

Well No.	KTL-01			KTL-02			KTL-04		
Parameters	Layer 1 Value	Layer 2 Value	Layer 3 Value	Layer 1 Value	Layer 2 Value	Layer 3 Value	Layer 1 Value	Layer 2 Value	Layer 3 Value
$P_{(avg.)}$(psia)	3493.0	3493.0	3493.0	3221.3	3221.3	3221.3	3490	3490	3490
P^*(psia)	3492.8	3492.8	3492.8	3219.9	3219.9	3219.9	3488.7	3488.7	3488.7
$P_{(syn)}$(psia)	3493.6	3493.6	3493.6	3221.9	3221.9	3221.9	3490.7	3490.7	3490.7
C_D	.165	.165	.165	23015.52	23015.52	23015.52	2074.818	2074.818	2074.818
K(md)	43	46	43	610	600	605	110	100	90
h (ft)	66	63	60	40	37	36	69	67	70
Kh(md.ft)	2838	2898	2640	24400	22200	21780	7590	6700	6300
S_d	-3.311	-2.50	-3.010	11	14	16	3	4	5
ω	0.1	0.08	0.09	0.1	0.6	0.9	0.1	0.8	0.9
λ	1.00e-06	1.5e-06	1.0e-06	1.00e-06	1.4e-06	1.6e-06	1.00e-06	1.5e-06	2.0e-06
X_e(ft)	12700	12790	12810	11820	11823	11833	11822	11831	11836
Y_e(ft)	2180	2190	2200	2370	2374	2385	2370	2379	2387
X_w(ft)	6250	6325	6380	5910	5920	5927	5315	5327	5340
Y_w(ft)	1011	1030	1042	1185	1189	1194	1183	1189	1190

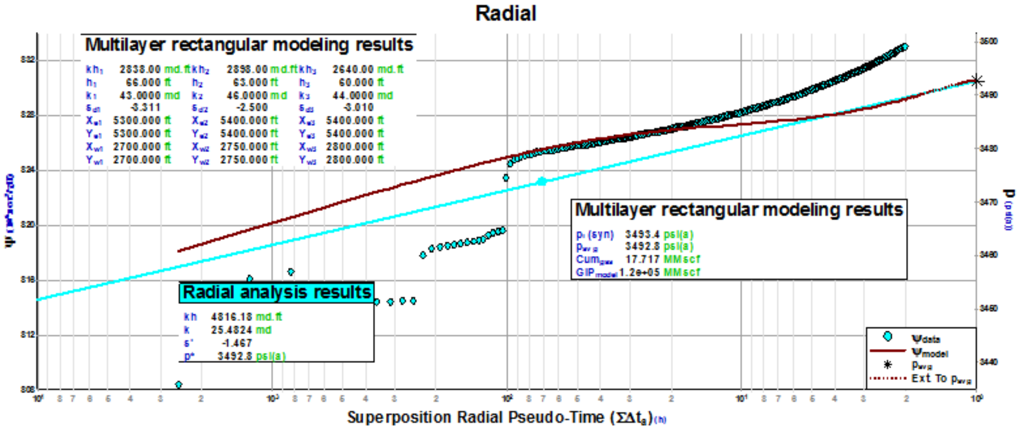

Figure-1: Semi log plot of multilayer model for pressure buildup test of KTL-01

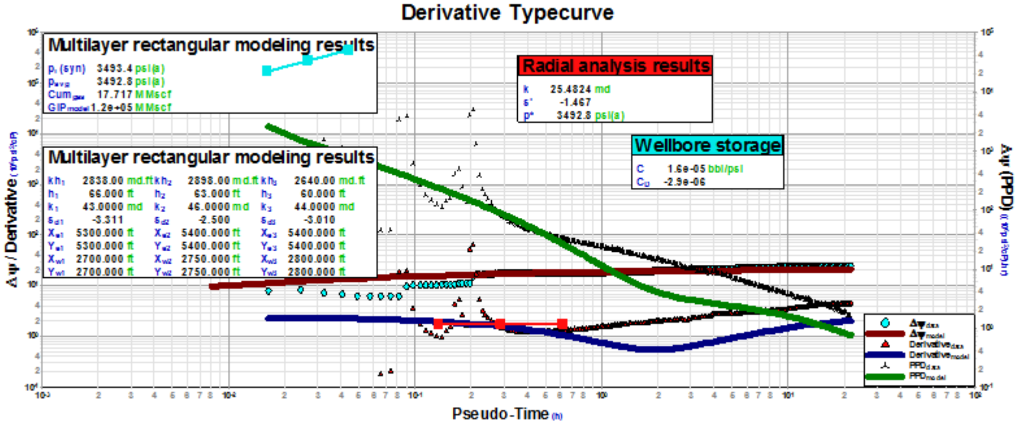

Figure-2: Pressure, Pressure derivative and Dimensionless pressure during buildup and multilayer model for KTL-01

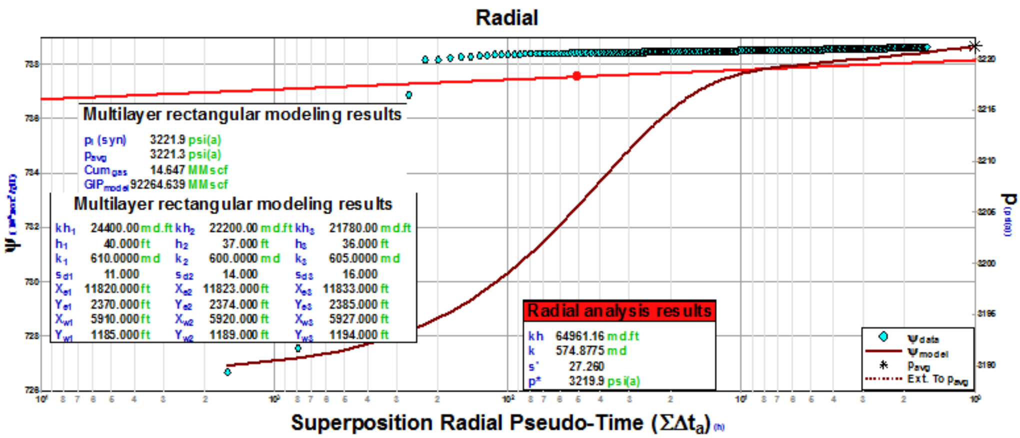

Figure-3: Semi log plot of multilayer model for pressure buildup test of KTL-02

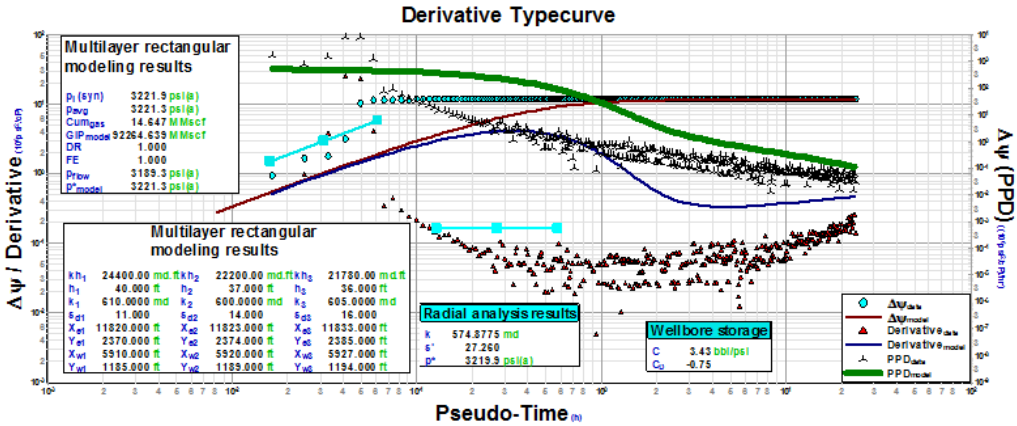

Figure-4: Pressure, Pressure derivative and Dimensionless pressure during buildup and multilayer model for KTL-02

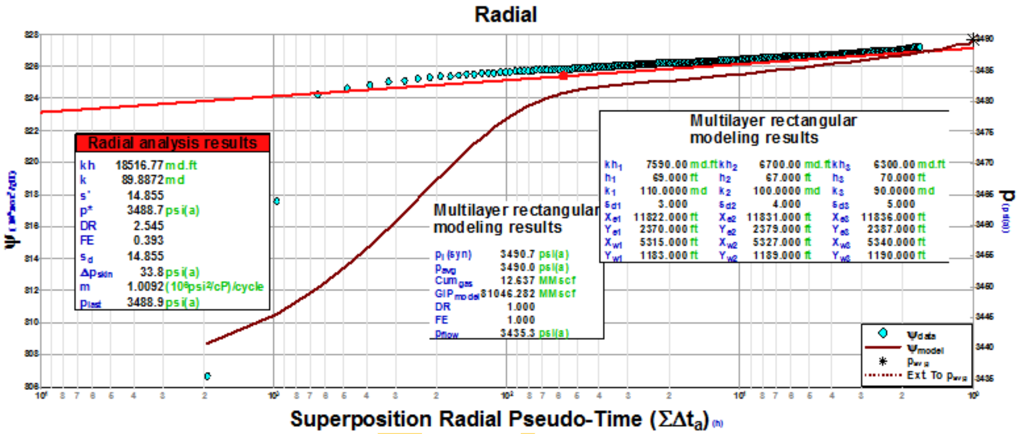

Figure-5: Semi log plot of multilayer model for pressure buildup test of KTL-04

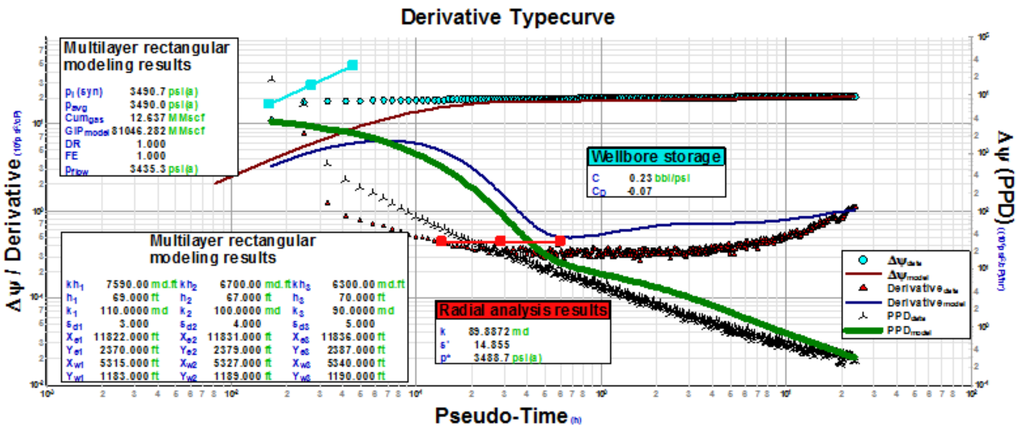

Figure-6: Pressure, Pressure derivative and Dimensionless pressure during buildup and multilayer model for KTL-04

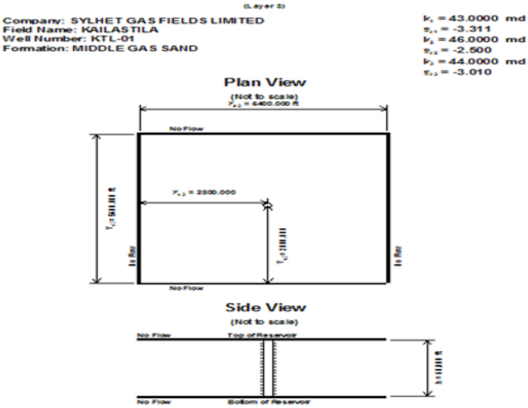

Figure 7: Plan view of layer of KTL-01

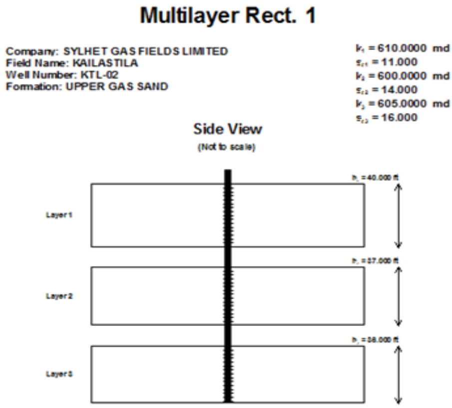

Figure 8: Side view of layers of KTL-02

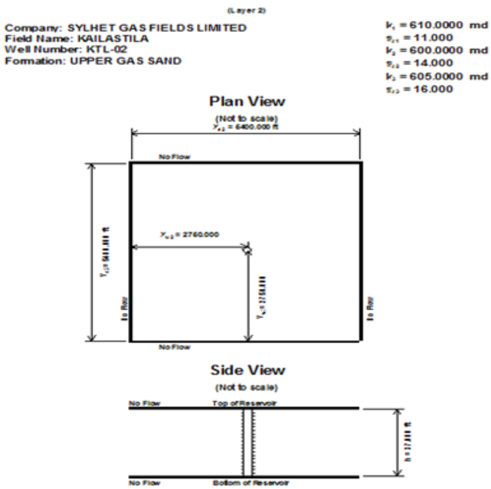

Figure 9: Plan view of layer of KTL-02

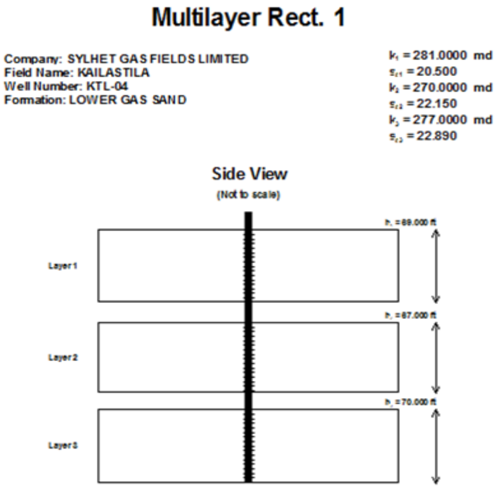

Figure 10: Side view of layers of KTL-04

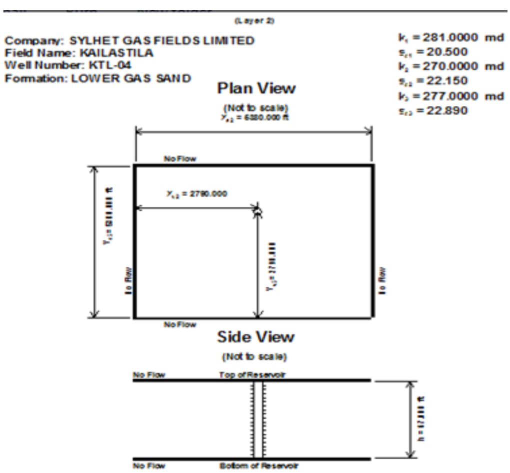

Figure 11: Plan view of layer of KTL-04