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Predicting Production Behavior of the Marcella Shale by Using Arps Equation

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Abstract

The behavior of the horizontal wells producing from Marcellus shale is not fully understood because of the limited production history. As a result a method of predicting the long term production is needed. A number of production decline curve analysis models have been proposed for application to unconventional gas reservoirs. The problem is that the reliable production prediction method are not available when production history from Marcellus shale horizontal wells is limited. In this study, production and completion data from Marcellus shale wells were collected to build a generic model The generic model was then used in conjunction with a commercial dual-porosity numerical model which include the adsorbed gas to simulate long term production profiles for Marcellus shale horizontal wells with multiple hydraulic fractured stages. Subsequently, the simulation of the production profiles were utilized to develop correlations for adjusting the conventional decline curve (Arps) constants (n, d_i, q_i) obtained from the limited production history to accurately predict the long term production performance. The impacts of the formation and fracture properties on the decline curve constants were investigated. Finally, the correlations were utilized to confirm the accuracy of the predicted production rates from a Marcellus shale horizontal well based on the available early production history.

Dedication

I dedicate this thesis to my parents, who without their support and believe in me, I would not be able to finish my Master and who without I would not be who I became. So, thank you and may god bless your souls.

Abdulhameed H. Alabdulkareem Khaledh D. Alohaly

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1 Introduction

The unconventional shale natural gas reservoirs has been recently considered economically attractive source of natural gas. Since 1970's, several government and privet organizations initiated the evaluation of the resources and the condition necessary to develop them (Gibbons 1985). Since then, the technology development to produce from low-permeability reservoirs has progressed significantly. One of the most important factor that made the production from the shale gas reservoirs economical is effective stimulation treatment. The main objective of the stimulation treatment is to obtain a large, highly fractures network that can produce from ultra-low permeability rock (Mashayekhi, 2014). First step of stimulating the reservoir is by making a multiple stage hydraulic fracture in the horizontal well. Horizontal wells are more cost effective in achieving commercial production from the shale than vertical wells. The reason is the horizontal wells allow more access to the formation than vertical wells and allow the application of multi-stage hydraulic fracturing treatments.

The prediction of the future production rate however challenging due to the limited production history from Marcellus Shale wells.. The industry is demanding better techniques to assist with forecasting accurate production prediction for horizontal wells with multiple fractures.

One of the techniques that has been used to predict the production rates is Decline Curve Analysis (DCA). Decline curve analysis is a common technique for predicting the future production rates and reserves of the conventional reservoirs which produce under boundary dominates flow. However, Shale is an unconventional reservoir. The application DCA to shale production data leads to over estimation of the production rates. So, DCA must be adjusted for the unconventional gas reservoirs to obtain a more accurate estimation of the future production rates. There are a number of DCA methods that are proposed for predicting the production rates from unconventional reservoirs. However, Arps equation has been found to provide a better fit to Marcellus shale production history and is a simpler technique comparing to other decline curve proposed for unconventional reservoir. Therefore, it is more convenient and practical to modify the Arps DCA method for predicting production behavior of Marcellus shale.

2 Literature Review

Decline curve analysis is widely applied for forecasting future production from low permeable formation. There are three types of decline curve during the boundary dominated flow (BDF): Exponential, Hyperbolic and Harmonic.

One of the most important decline curve method is Arps decline curve. Arps applied a mathematical treatment to coalesce these earlier concepts to unify the theory on the rate-time cumulative production characteristics of production decline curve (Poston. Poe Jr, 2008).

Johnson and Bollens (1928) and Arps (1945) presented the loss ratio (rate of change of the reciprocal of instantaneous decline rate) respectively as: $\frac{1}{D} = -\frac{q}{dq/dt}$ ……… ……………… (1)

$$\frac{1}{D} = -\frac{q}{dq/dt} \text{ ……… ……………… } (1)$$

and the derivative of the loss-ratio:

$$n = \frac{d}{dt}\left[-\frac{q}{dq/dt}\right] \text{ …………..…… } (2)$$

The value of n ranges from *0* to *1*. When $n = 0$, which means D is constant, Eq. 1 leads to an exponential decline which can be derived for the case of BDF in close closed reservoir containing a constant compressibility liquid and being produced at constant wellbore flowing pressure (Ilk, 2008). When $0 < n < 1$, then the decline curve will be hyperbolic. And for$n = 1$, it will result in harmonic decline.

Assuming constant loss ratio Arps derivative his hyperbolic decline model as :

$$q = q_i(1 + nd_i t)^{-1/n} \text{ ……………... } (3)$$

Usually n is less than 1 (). However, when Arps equation applied to transient production data from the shale reservoir, the estimated value of n is greater than *1* This seems to give a better matching to the field data from the transient-flow period. For example, the liner flow which commonly observed in shale gas reservoirs have n value of 2.

3 Objective and Methodology

3.1 Objectives

The main goal of this study is to develop a reliable method for application of Arps decline curves for predicting the long-term production performance of multiple hydraulic fracture in horizontal well in Marcellus shale. Therefore, the constant in Arps equation Eq. 3 (n , d_i *and* q_i) determined from the early limited production history should be modified to predict reliable long-term production rates.

3.2 Methodology

To achieve the objective of the study three steps were implemented:

1) A reservoir model was developed using a commercial simulator (Eclipse). The model simulated 30-year production history from a horizontal well with the multiple hydraulic fracture in Marcellus Shale Two scenarios for hydraulic fracture stage spacing were considered in the model 500 feet or 7 stages and 250 feet or 13 stages. A series values for the fracture half-length (X_f) and natural fracture permeability (K) were used to determine the impacts of hydraulic and natural fractures on production decline behavior.
2) The Arps decline curve was used to match the 30-years production profile and determine the decline curve constant n_{30}, d_{i30}, *and* q_{i30}.
3) A number of correlations were developed to adjust Arps decline curve constant estimated from the early and limited production profile to predict the long term production profile.

3.2.1 Reservoir Model Development

The first step in this study was to develop the reservoir model in the simulator (Eclipse) by inserting the reservoir parameters (length, width, porosity, permeability…).The formation parameters are summarized in Table 1.

Table 3- 1: Base Model Parameters

Base Model Parameters		
Reservoir Parameters		Ranges of Properties
Layer Name	Marcellus	
Formation Thickness, ft.	75	
Reservoir Length, ft.	4,000	
Reservoir Width, ft.	2,000	
Horizontal well, ft.	3,000	
Initial Reservoire pressure, psia	3,000	
Gas Saturation, frac.	0.85	
Fissure Porosity, frac.	0.005	
Matrix Porosity, frac.	0.05	
Fissure perm, i, j and k, md	0.002, 0.002, 0.0002	0.004, 0.004, 0.0004 0.006, 0.006, 0.0006
Matrix perm, i, j and k, md	0.0004, 0.0004, 0.00004	
Fissure Spacing, σ, 1⁄ft^2	0.0073	
Hydrulic Fracture Propeties		
Halt-Length, ft.	500	300, 400, 600
Width, in.	0.01	
Top of Fracture, ft.	7000	
Bottom of Fracture, ft.	7075	
Permeability, md	20,000	
Porosity, frac.	0.2	
Nmber of Fracture Stages	7 & 13	
Well Production Controls		
P_wf psia	500 psi	
Adsorption		
Diffusion Coefficient, ft^2/day	1	
Sorption Time, day	62	
Longmuir Pressure, psia	635	
Longmuir Concentration, MSCF/ton	0.09	

3.2.2 Application of DCA Techniques to Simulated Data:

Towler proposed a nonlinear-regression method in Microsoft Excel (Excel-Solver) to find the best fitting for the constant in Eq. 3. A spreadsheet was set up containing column for predicted flow rate by Arp's equation q', the errors squared $(q - q')^2$and total errors squared $\left(q - q_{avg}\right)^2$, where q correspond to the flow rate generated by the simulator. Also, A cell to generate the regression coefficient R^2 by using Eq. 4:

$$R^2 = 1 - \frac{S_{SE}}{S_{ST}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

Where:

S_{SE}: Sum of errors squared $\sum(q - q')^2$.

S_{ST}: Sum of total error squares $\sum\left(q - q_{avg}\right)^2$.

$Table$ 3–2 illustrate a sample from the spreadsheet.

Table 3- 2: Excel Sheet Example

n	di	qi	R2	avg q	SSE	SST
1.5768676	0.00816631	5518.12	0.997921	535.4247	2242339	1.08E+09

time(days)	qt(MSCF/Day)	qt'	(qt-qt')2	(qt-q)2
0.9993156	6276.665	5473.556	644983.7	39396524
1.4989733	5878.2607	5451.62	182022.6	34553949

By using the Solver in Microsoft-Excel the value of R^2 will be changed to obtain the best values for n, d_i and q_i that will minimizes the difference between q' and q.

3.2.3 Adjusting the Arps DCA Constants in

The values of n, d_i and q_i were estimated using production profile for different number of years including 2, 3, 4, 5 and10. The ratio’s ${}^{n_t}/_{n_{30}}$, ${}^{d_{it}}/_{d_{i30}}$ and ${}^{q_{it}}/_{q_{i30}}$ were then determined for various cases, i.e. different fracture spacing, different fracture half-length, and different natural fracture permeability. The results are summarized in Table 3-3, 3-4, 3-5 and 3-6 and Figures 3-1, 3-2 and 3-3.

Table 3- 3: The Ratio of n, d_i and q_i on 300 ft Half-Length

HL frac.= 300 ft	n/n30	di/di30	qi/qi30
2	2.188137	23.66632	1.528142
3	1.859123	13.77332	1.41205
4	1.306546	2.46384	1.130181
5	1.074711	1.30464	1.050539
10	1.023293	1.209235	1.027912
30	1	1	1

Table 3- 4: The Ratio of n, d_i and q_i on 400 ft Half-Length

HL frac.=400 ft	n/n30	di/di30	qi/qi30
2	2.085751	12.38367	1.327541
3	1.806843	6.624521	1.21273
4	1.298266	2.019614	1.074688
5	1.074011	1.246233	1.024856
10	1.017169	1.092517	1.011294
30	1	1	1

Table 3-5: The Ratio of n, d_i and q_i on 500 ft Half-Length

HL frac.=500 ft	n/n30	di/di30	qi/qi30
2	2.044121	5.986296	1.175878
3	1.703706	3.631642	1.126267
4	1.235375	1.52191	1.042353
5	1.047335	1.023602	1.002515
10	1.003932	1.014802	1.001727
30	1	1	1

Table 3-5: The Ratio of n, d_i and q_i on 300 ft Half-Length

HL frac.=600 ft	n/n30	di/di30	qi/qi30
2	1.858225	3.880315	1.127027
3	1.441842	2.143855	1.074895
4	1.122402	1.25172	1.023664
5	1.005064	1.008044	1.001067
10	1.003732	1.002598	1.000788
30	1	1	1

Figure 3- 1: The Impact of the Hydraulic Fracture Half-length on the n Ratios

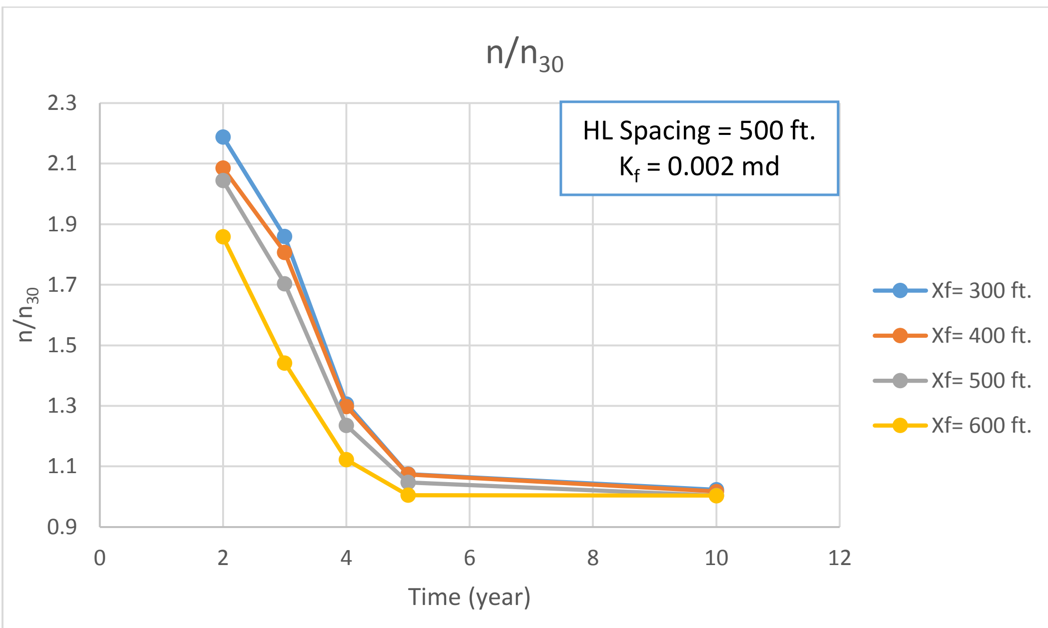


Figure 3- 2: The Impact of the Hydraulic Fracture Half-length on the d_i Ratios

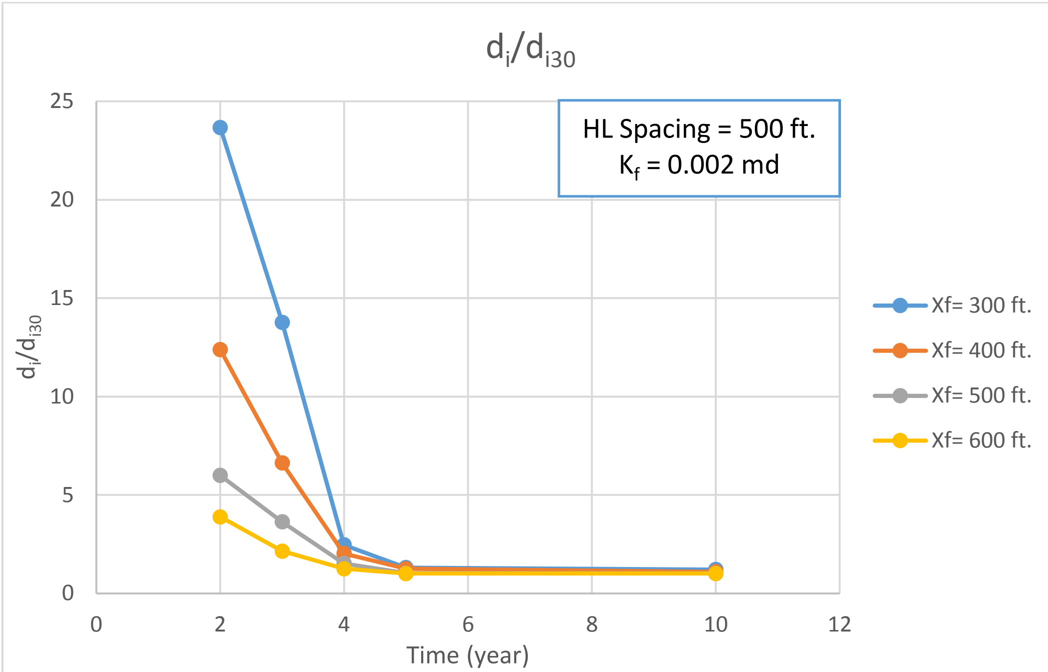
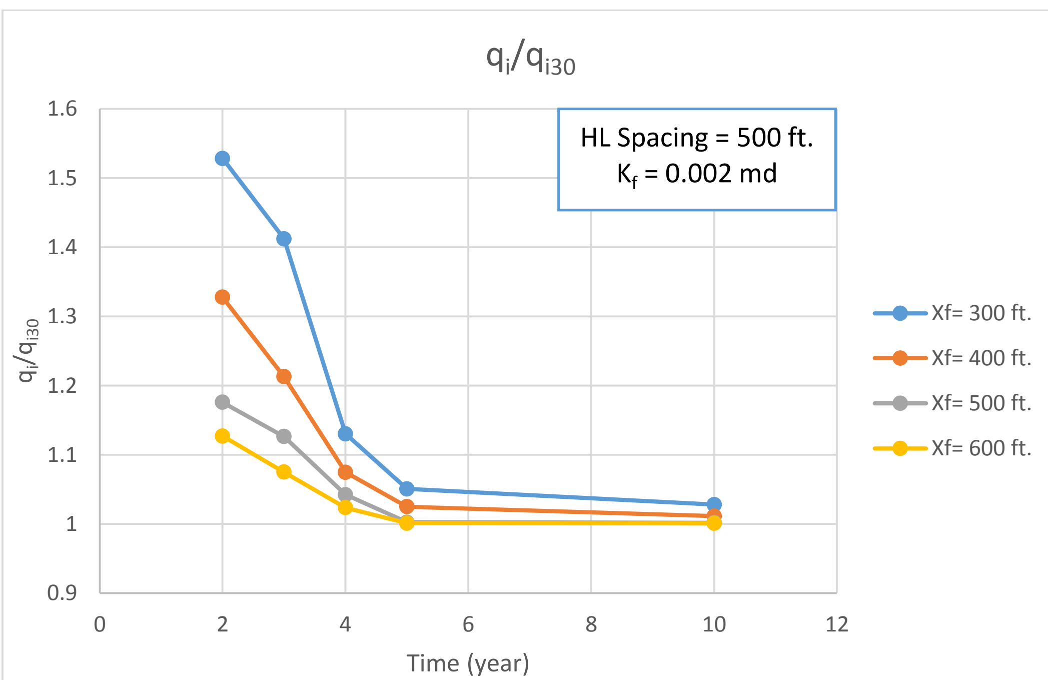


Figure 3- 3: The Impact of the Hydraulic Fracture Half-length on the q_i Ratios



3.2.4 Confirmation with Field Data

In order to investigate the reliability of using ${n_t}/{n_{30}}$, ${d_{it}}/{d_{i30}}$ and ${q_{it}}/{q_{i30}}$, graphs to adjust the Arps constants, the production data from a a Marcellus shale well was utilized.

The available production data was history matched using the reservoir model developed in the first step. Upon history matching, the reservoir parameters were estimated and used in the model to predict the extended production profile (30-year). The production data was also used to determine the decline curve constants, i.e. n, d_i and q_iThen, the correlations were used to estimate the ratio's, ${n_t}/{n_{30}}$, ${d_{it}}/{d_{i30}}$ and ${q_{it}}/{q_{i30}}$. The ratios were then used to determine$n_{30}, d_{i30}and\ q_{i30}$.

The decline curve was then used with $n_{30}, d_{i30}and\ q_{i30}$ to predict the long term production profile. The comparison of the production profiles obtained from decline curve analysis and simulator was then utilized to verify the reliability of the prediction.

4 Results and Discussion

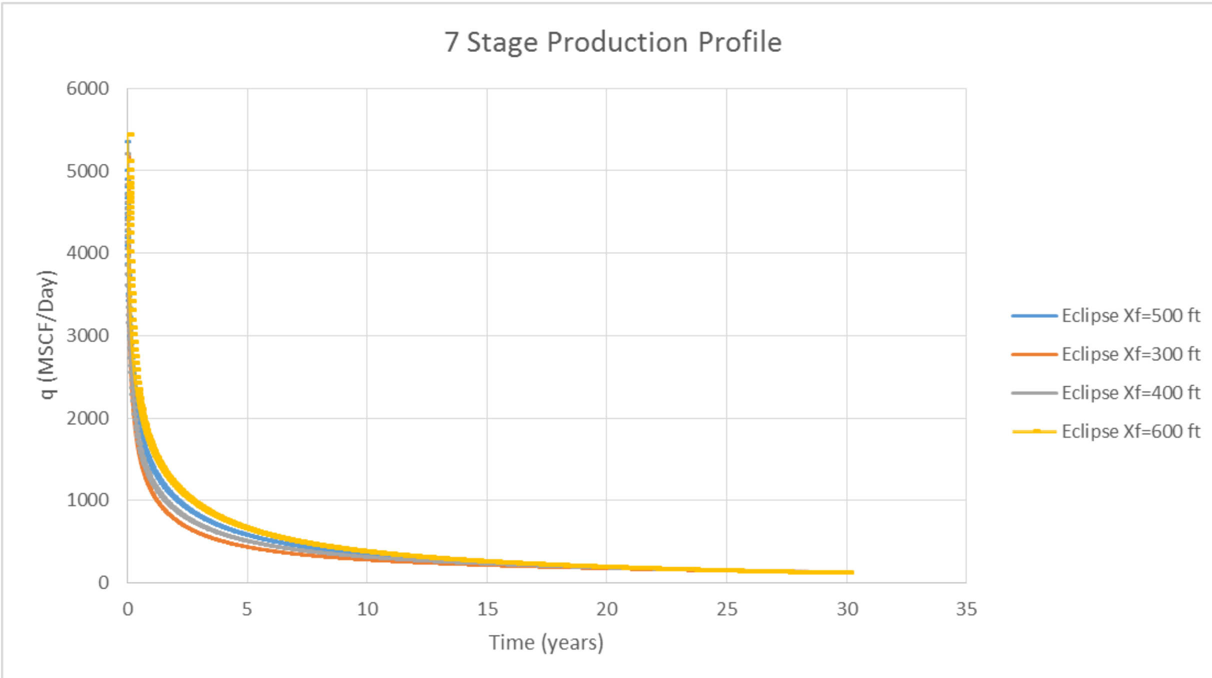
4.1 Development of Marcellus Shale Reservoir Model in Simulator (Eclipse)

With both scenarios for different hydraulic fracturing stages (7 &13), number of models were built to study more the behavior of the DCA and the accuracy of its outcome with different models.

4.1.1 Seven Stages Model

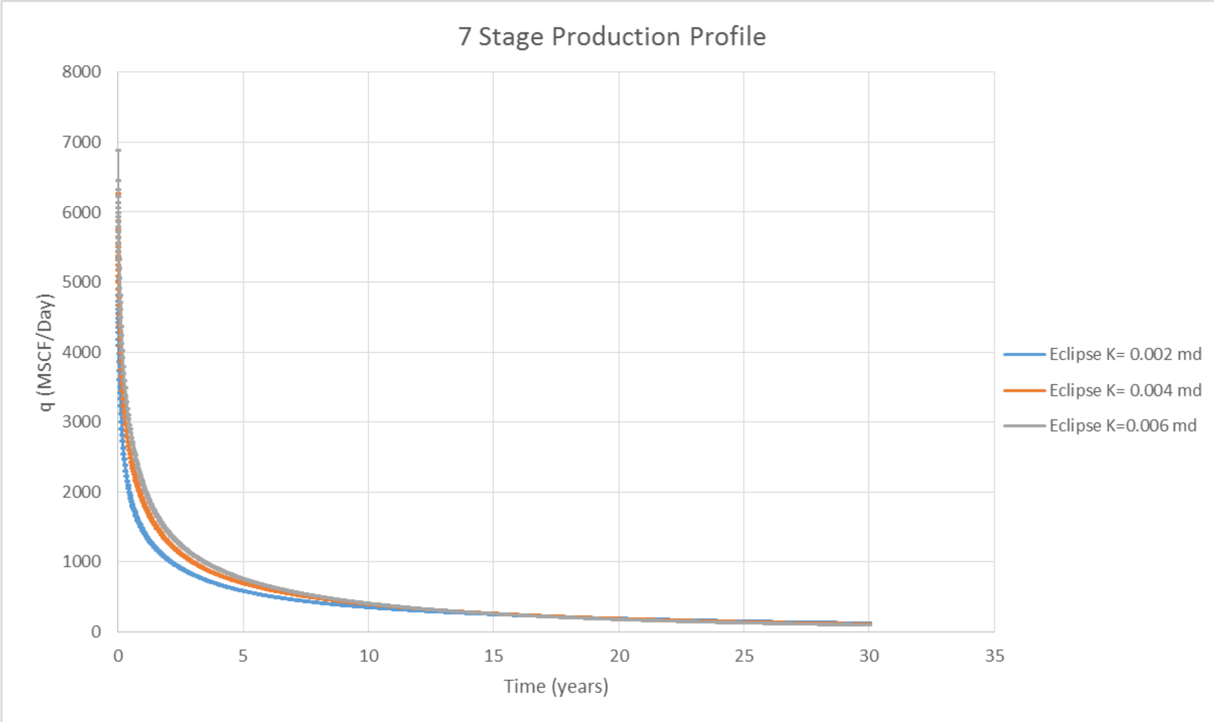
In figure 4-1 shows the outcome that the simulator (Eclipse) for the behavior of the seven stage scenario with different half-length hydraulic fracture

Figure 4- 1: the Outcome of Simulator (Eclipse) Seven Stage Profile Production for Different Half-Length.



In figure 4-2 shows the outcome that the simulator (Eclipse) for the behavior of the seven stage scenario with different permeability to the base model.

Figure 4- 2: the Outcome of Simulator (Eclipse) Seven Stage Profile Production for Different Permeability.



4.1.2 Thirteen Stages Model

In figure 4-3 shows the outcome that the simulator (Eclipse) for the behavior of the thirteen stage scenario with different half-length hydraulic fracture.

Figure 4- 3: the Outcome of Simulator (Eclipse) Thirteen Stage Profile Production for Different Fracture Half-ength.

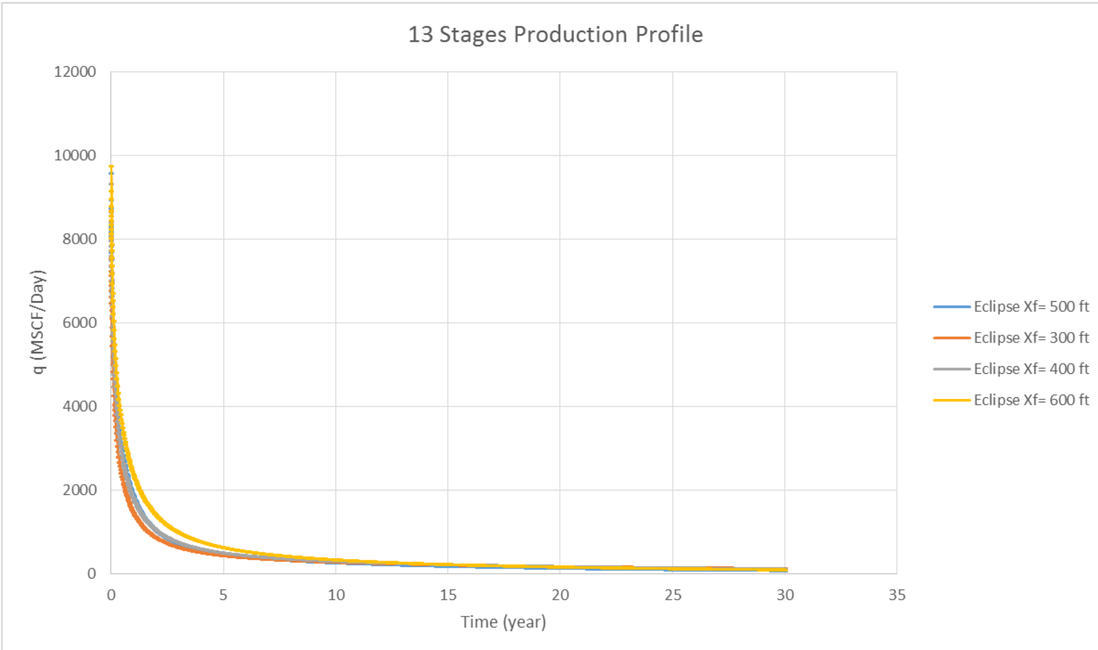
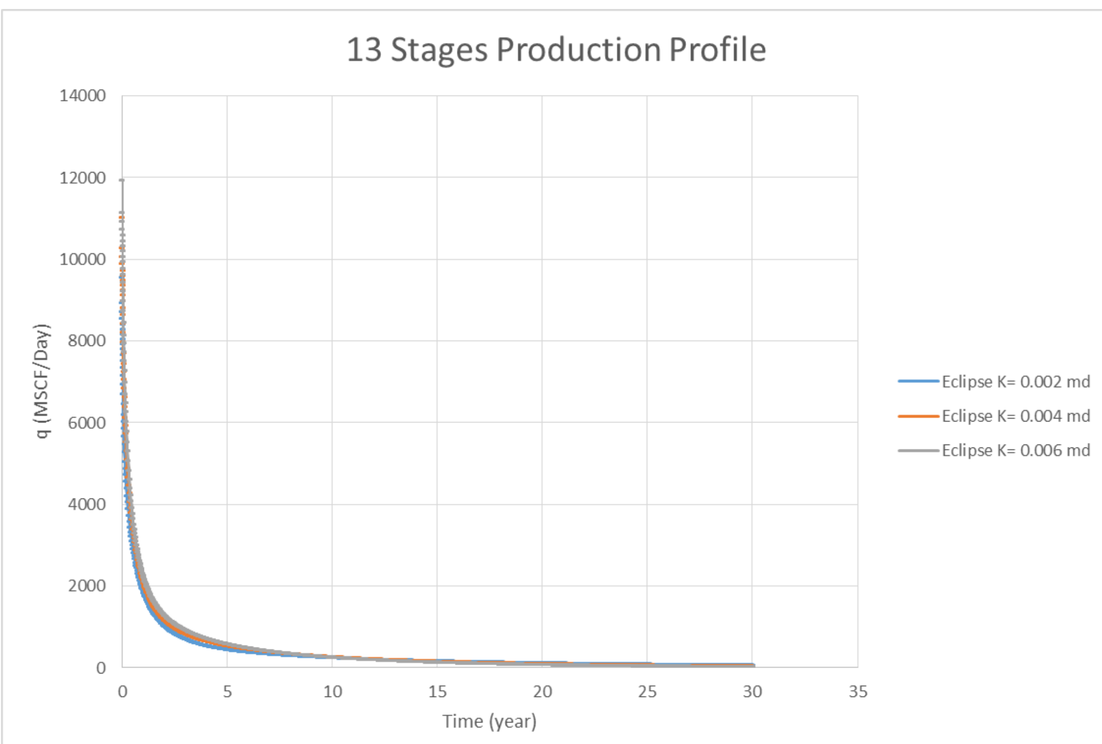


Figure 4- 4: the Outcome of Simulator (Eclipse) Thirteen Stage Profile Production for Different Permeability.



4.2 Comparing Results of Simulated Model with Arps

Each of the simulated outcome for each model in both stages were used to find out the Arps flow rates values by using Microsoft-Excel Solver to find the best values for Arps constants $n, d_i \; and \; q_i$to get best match to the simulation result, which they will be refer to as $n_{30}, d_{i30} and \; q_{i30}$. In Figure 4-5 shows the base model for seven stage hydraulic fracture from simulation and from Arps DCA and in figure 4-6 shows the base model for thirteen stage hydraulic fracture from simulation and from Arps DCA. The rest of the comparison between simulation production profile and Arps will be in Appendix.

4.2.1 Seven Stage Model

In figure 4-5 the simulation model and the Arps that has been found are closely match. In Table 4-1 shows the constant in Arps DCA which will give the best match to the curve the simulation is giving.

This Arps DCA and simulation matching will be done for all scenarios to get the values of Arps DCA constants at 30 years.

Figure 4- 5: Arps DCA Simulated Data History Matching for 7-Stages Base Model.

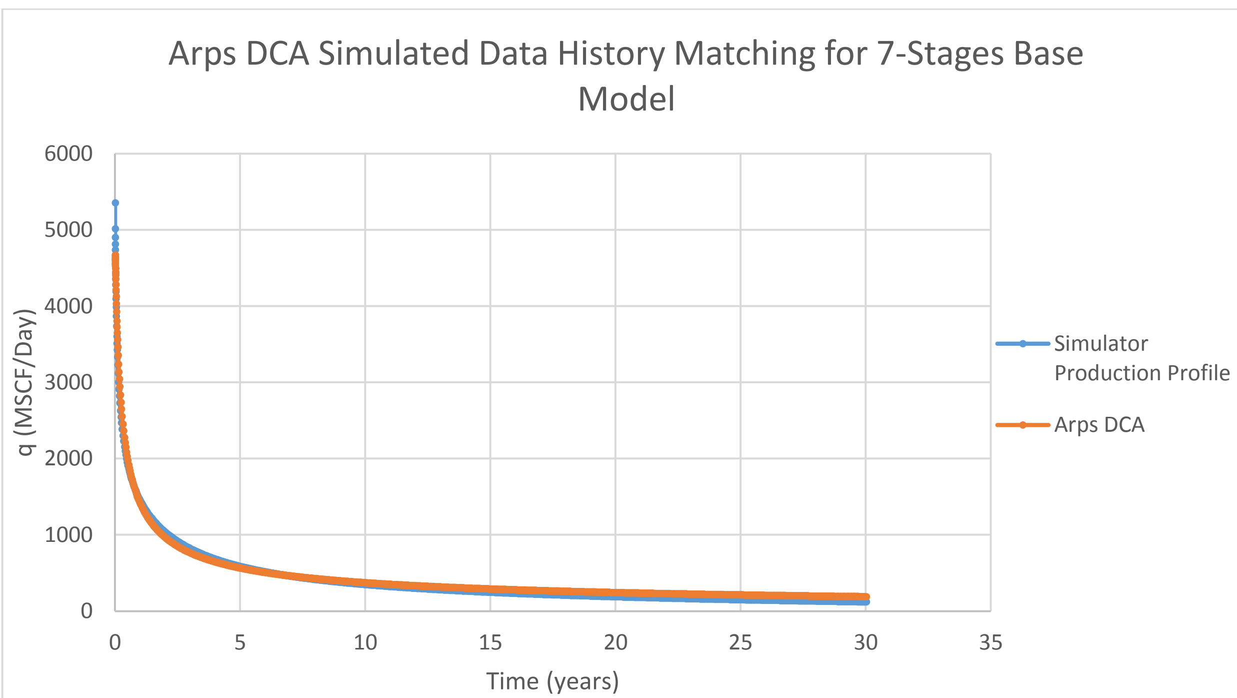


Table 4- 1: Arps DCA Constant Values for the Base Model for 7-stages Model.

n	d_i	q_i	R^2
1.632323	0.010313	4720.323086	0.997277

4.2.2 Thirteen Stages Model

In figure 4-6 the simulation model and the Arps that has been found are closely match. In Table 4-2 shows the constant in Arps DCA which will give the best match to the curve the simulation is giving.

This Arps DCA and simulation matching will be done for all scenarios to get the values of Arps DCA constants at 30 years.

Figure 4- 6: Arps DCA Simulated Data History Matching for 13-Stages

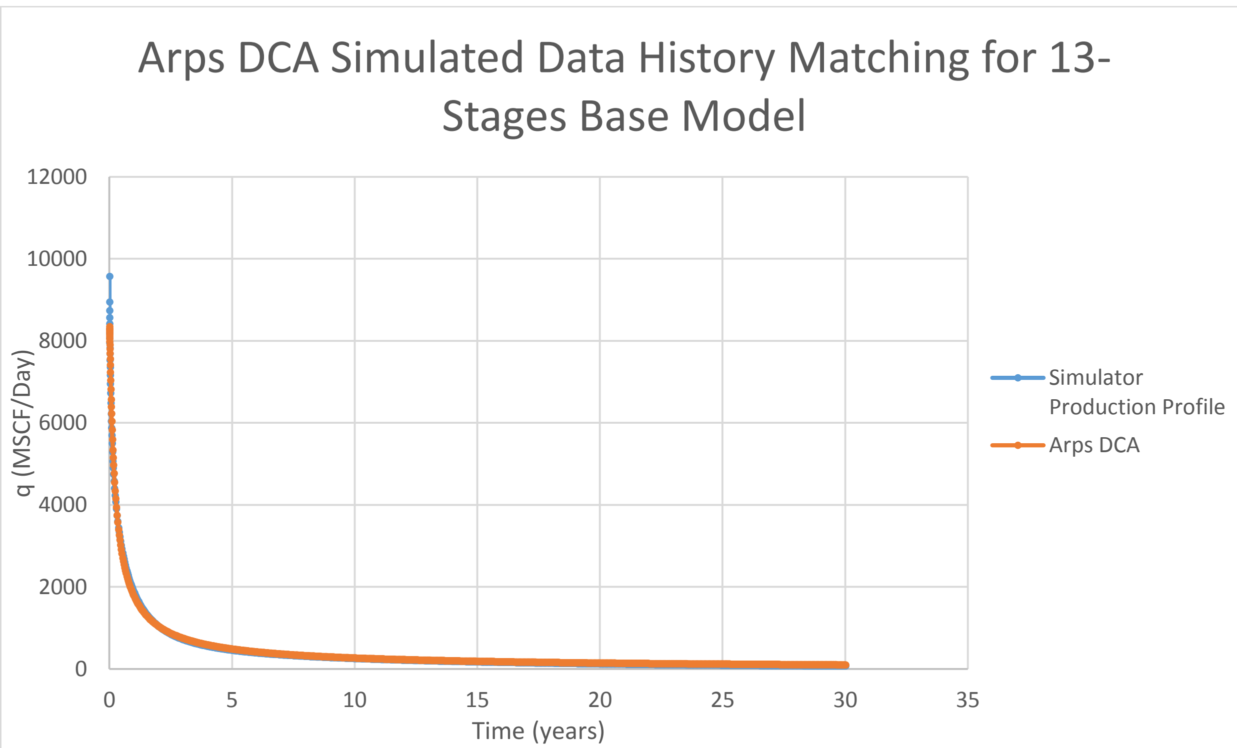


Table 4- 2: Arps DCA Constants Values for the Base Model for 13-stages Model.

n	d_i	q_i	R^2
1.13398	0.011724089	8444.618	0.99762

4.3 Application of Arps DCA Model to Limited Production Profile

Arps DCA Model Has three constants as it has mentioned before $n, d_i \; and \; q_i$. It is important to know the affection of those constants on early stages of the productions. At first the Microsoft Excel-Solver used to get a good answer of those constants. Then, a little of changes need to be done to get a better fit to the actual results to get a good values for Arps DCA constants which will give a good results of q' that matches q. However, at early stages of the production, the constant values will be higher than late stages. So, the production data has been reduced to 2, 3, 4, 5 and 10 years of production time in order to get a correlation between the decline curves' constants versus the production time. The Constant values that will give a highest values of regression coefficientR^2, will be used as the constant in each early stages that has been chosen.

4.3.1 Seven Stage Model

The simulation scenarios that were built for seven stage model now will be used to get the constants values for Arps DCA in different number of years with changing the half-length fracking in the base model and making the permeability constant (300 ft., 400 ft. and 600 ft.). That will provide with values that needed to build the ratio graph between $^{n_t}/_{n_{30}}, ^{d_{it}}/_{d_{i30}} \; and \; ^{q_{it}}/_{q_{i30}}$ vs Time. In figure 4-7, 4-8 and 4-9 will show the graph of the $^{n_t}/_{n_{30}}, ^{d_{it}}/_{d_{i30}} \; and \; ^{q_{it}}/_{q_{i30}}$ for different fracking half-length and with the same permeability. Table 4-3 shows the constants values of each different scenarios in seven frack stage model of which they were used to get graphs in figure 4-7, 4-8 and 4-9.

Figure 4- 7: Ratio of $^{n_t}/_{n_{30}}$ vs Time for 7-Stages Fracks with Different Half-length Fracking

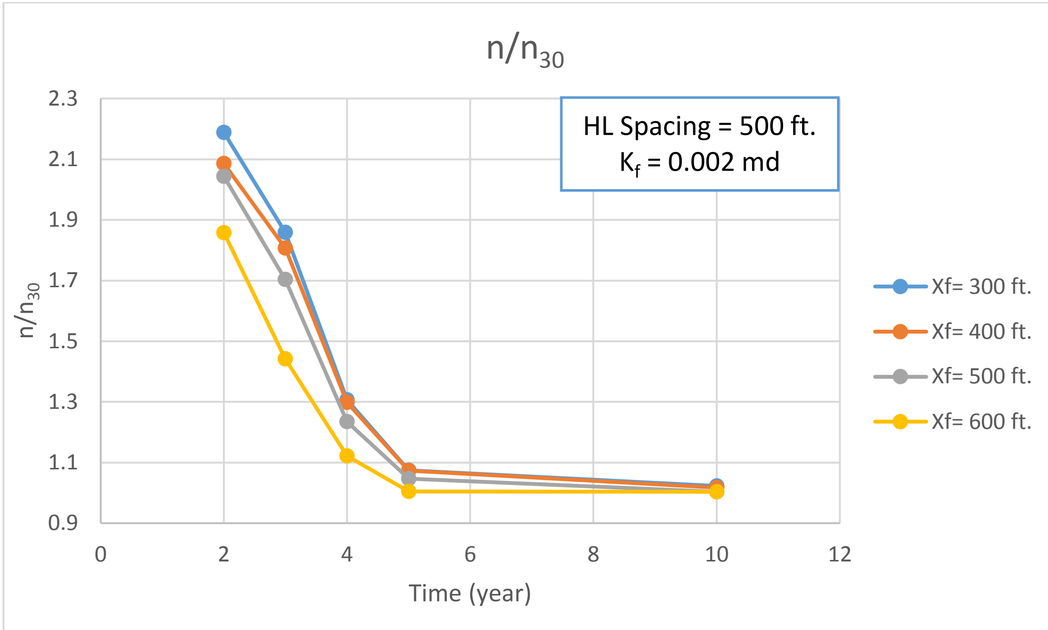


Figure 4- 8: Ratio of $^{d_{it}}/_{d_{i30}}$ vs Time for 7-Stages Fracks with Different Half-length Fracking.

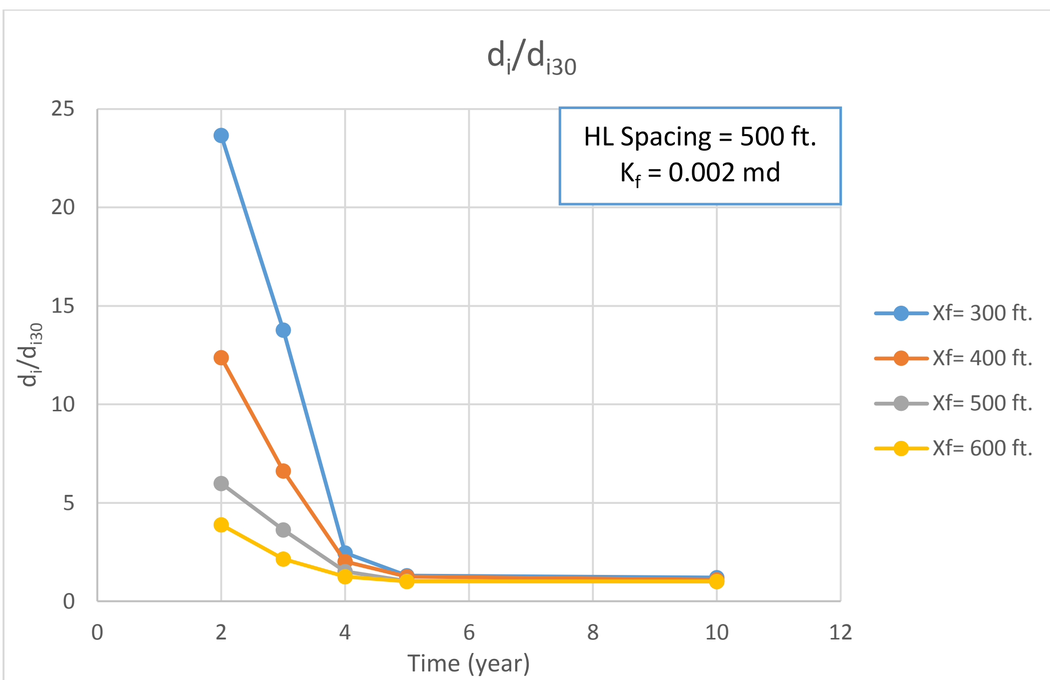


Figure 4- 9: Ratio of $^{q_{it}}/_{q_{i30}}$ vs Time for 7-Stages Fracks with Different Half-length Fracking.

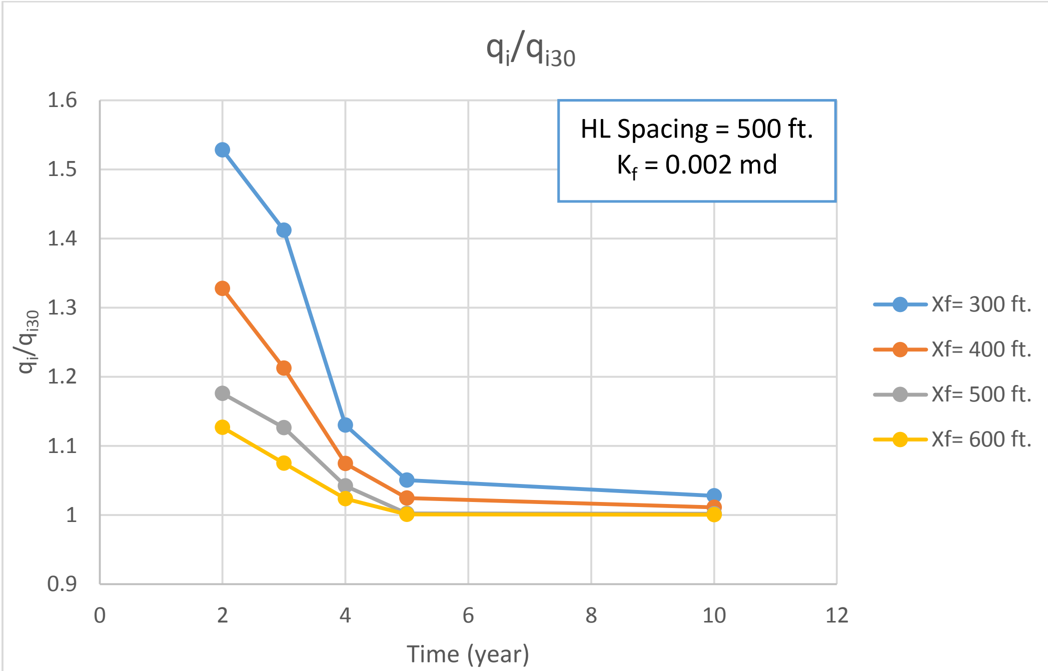


Table 4- 3: Arps DCA Constant Values for 7-Stages Model with Different Half-Length Fracking.

7 fracture Base Model				
years	n	di	qi	R^2
2	3.336666	0.061736	5.550525	0.995123
3	2.781000	0.037453	5.316346	0.996979
4	2.016532	0.015695	4.920243	0.999118
5	1.70959	0.010556	4.732195	0.997244
10	1.638742	0.010466	4.728476	0.997178
30	1.632323	0.010313	4.720323	0.997277

7 fracture Xf= 400 ft Model				
years	n	di	qi	R^2
2	3.63875	0.16942	6.117846	0.990138
3	3.152174	0.09063	5.588747	0.991561
4	2.264923	0.02763	4.952597	0.998784
5	1.873694	0.01705	4.722951	0.998689
10	1.774527	0.014947	4.660449	0.998038
30	1.744575	0.013681	4.608403	0.997877

7 fracture Xf= 300 ft Model				
years	n	di	qi	R^2
2	4.035268	0.460375	6.905707	0.981235
3	3.428514	0.267929	6.381087	0.981887
4	2.409477	0.047928	5.107313	0.996172
5	1.981935	0.025379	4.747408	0.99886
10	1.887114	0.023523	4.645158	0.998123
30	1.844157	0.019453	4.519023	0.998389

7 fracture Xf= 600 ft Model				
years	n	di	qi	R^2
2	2.917537	0.028748	5.314027	0.998566
3	2.263789	0.015883	5.068217	0.999366
4	1.762245	0.009274	4.826657	0.997736
5	1.578017	0.007468	4.720113	0.996063
10	1.575926	0.007428	4.718795	0.995973
30	1.570067	0.007409	4.715082	0.996362

Now, the half-length of the fracking will be constant, but the permeability will be changed (0.004 md and 0.006 md). That will provide with values that needed to build the ratio graph between ${}^{n_t}/_{n_{30}}, {}^{d_{it}}/_{d_{i30}}$ and ${}^{q_{it}}/_{q_{i30}}$ vs Time. In figure 4-10, 4-11 and 4-12 shows the ratio graph between ${}^{n_t}/_{n_{30}}, {}^{d_{it}}/_{d_{i30}}$ and ${}^{q_{it}}/_{q_{i30}}$ and Time. While in Table 4- 3 shows the Constants values of each different scenarios in seven frack stages model of which the graphs in figure 4-10, 4-11 and 4-12 were used to build.

Figure 4- 10: Ratio of ${}^{n_t}/_{n_{30}}$ vs Time for 7-Stages Fracks with Different Fracking Permeability.

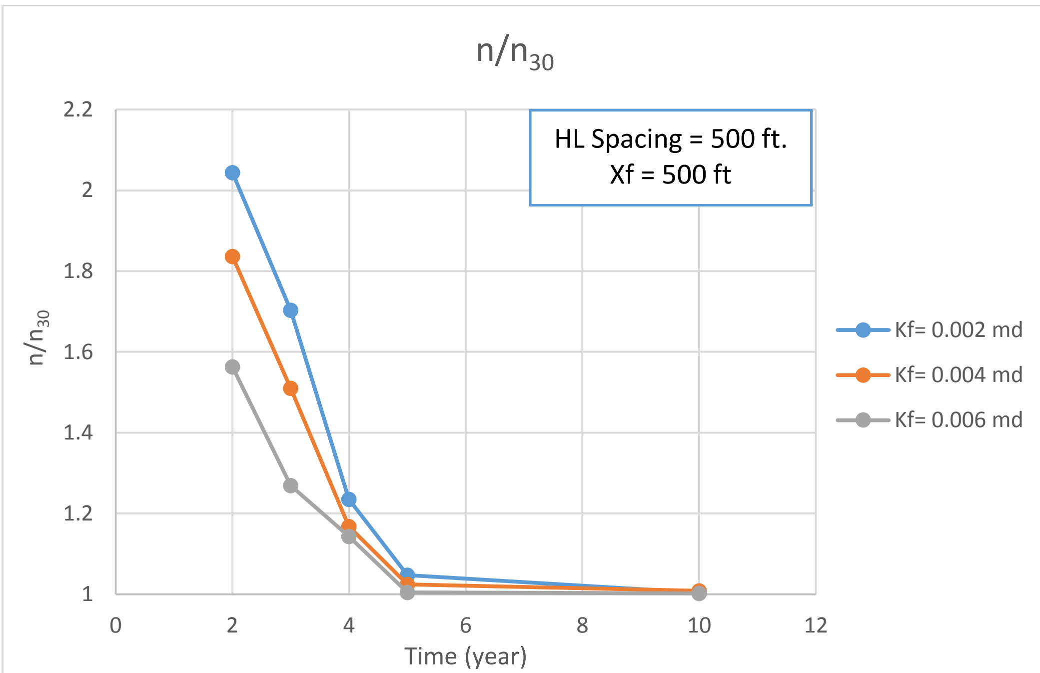


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Figure 4- 11: Ratio of $^{di_t}/_{di_{30}}$ vs Time for 7-Stages Fracks with Different Fracking Permeability.

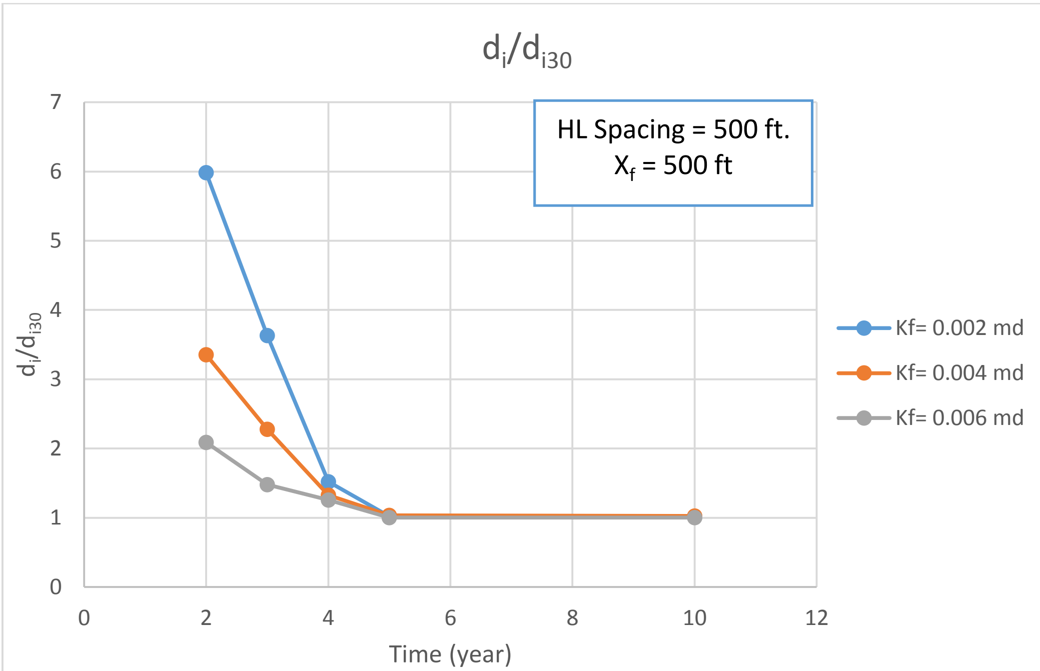


Figure 4- 12: Ratio of $^{q_{it}}/_{q_{i30}}$ vs Time for 7-Stages Fracks with Different Fracking Permeability.

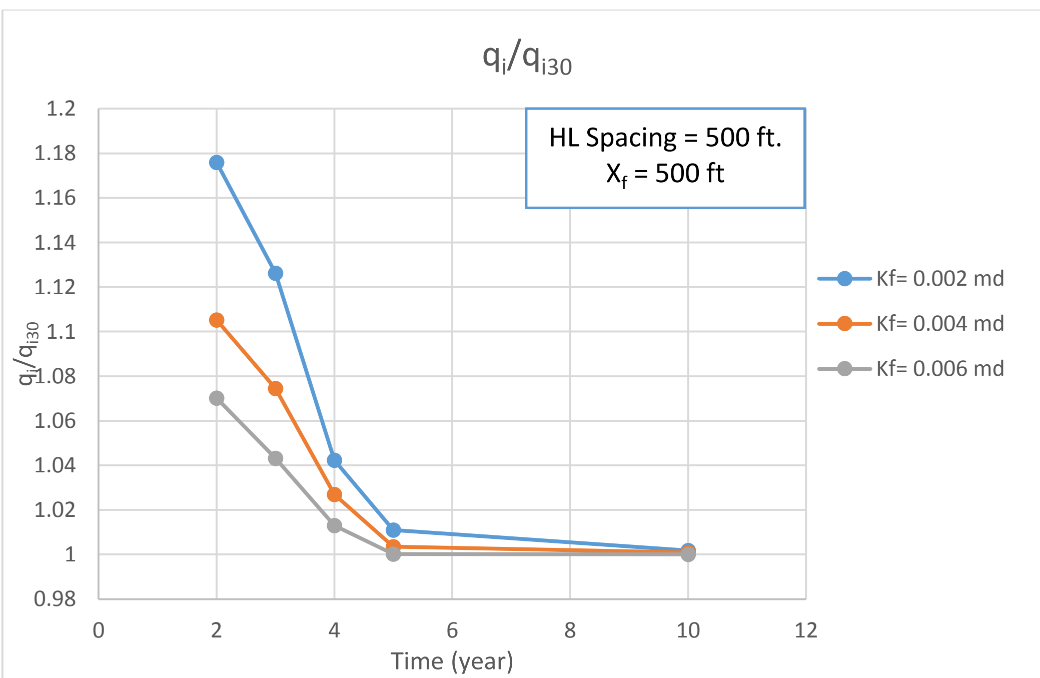


Table 4- 4: Arps DCA Constant Values for 7-Stages Model with Different Fracking Permeability.

7 fracture Base Model				
years	n	di	qi	R^2
2	3.336666	0.061736	5.550525	0.995123
3	2.781000	0.037453	5.316346	0.996979
4	2.016532	0.015695	4.920243	0.999118
5	1.70959	0.010556	4.732195	0.997244
10	1.638742	0.010466	4.728476	0.997178
30	1.632323	0.010313	4.720323	0.997277

7 fracture K= 0.006 md Model				
years	n	di	qi	R^2
2	2.447434	0.016528	6.483647	0.998772
3	1.98762	0.011691	6.319877	0.998926
4	1.790291	0.009929	6.137341	0.998503
5	1.572639	0.007917	6.059322	0.998317
10	1.56931	0.007912	6.058741	0.997337
30	1.565917	0.007904	6.058374	0.998347

7 fracture K= 0.004 md Model				
years	n	di	qi	R^2
2	2.895489	0.027416	6.099103	0.997692
3	2.380676	0.018624	5.92913	0.99829
4	1.841387	0.010831	5.666724	0.998723
5	1.615514	0.008467	5.537608	0.997971
10	1.590097	0.008377	5.523266	0.99746
30	1.576868	0.008166	5.51812	0.997921

4.3.2 Thirteen Stage Model

Doing exactly the same thing that has been done in the seven stage model to find $^{n_t}/_{n_{30}}, ^{d_{it}}/_{d_{i30}}$ *and* $^{q_{it}}/_{q_{i30}}$ vs Time. Figure 4-13, 4-14 and 4-15 will show the graph of $^{n_t}/_{n_{30}}, ^{d_{it}}/_{d_{i30}}$ *and* $^{q_{it}}/_{q_{i30}}$ vs Time for different fracking half-length and with the same permeability. In Table 4-3 shows the constants at each different model in multiple number of years. The Table 4-3 was used to build Figure 4-13, 4-14 and 4-15.

Figure 4- 13: Ratio of $^{n_t}/_{n_{30}}$ vs Time for 13-Stages Fracks with Different Half-length Fracking.

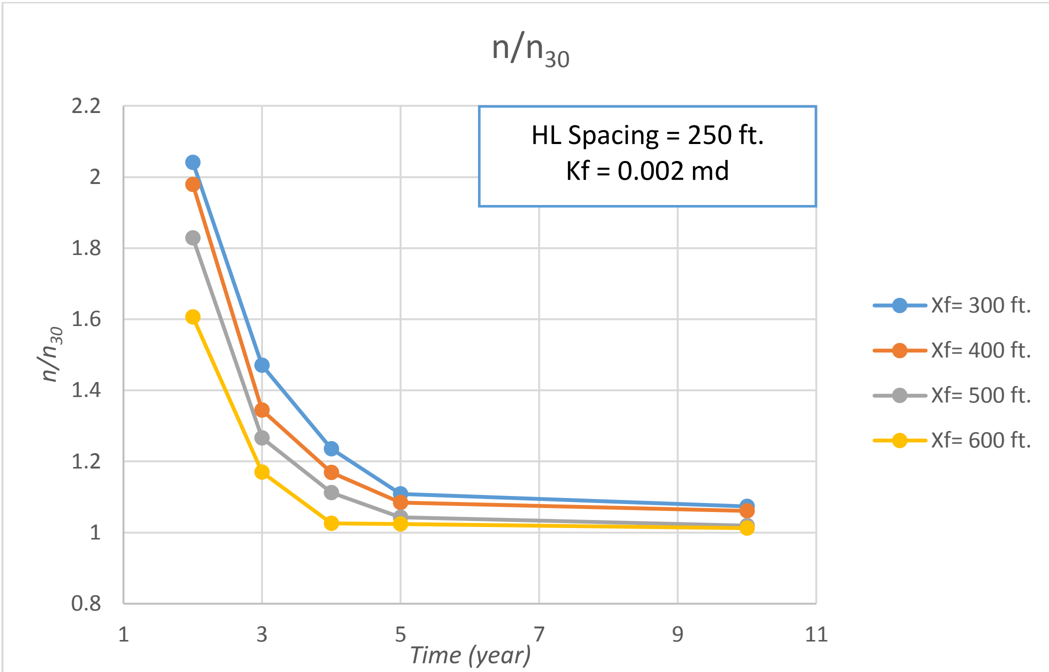


Figure 4- 14: Ratio of $^{d_{it}}/_{d_{i30}}$ vs Time for 13-Stages Fracks with Different Half-length Fracking.

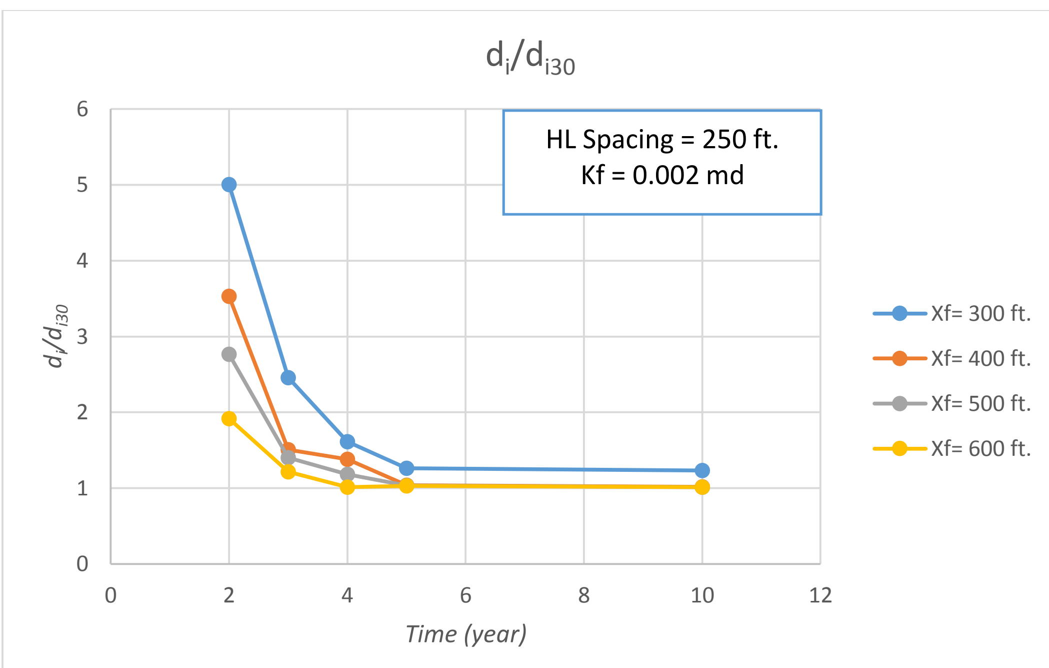


Figure 4- 15: Ratio of $^{d_{it}}/_{d_{i30}}$ vs Time for 13-Stages Fracks with Different Half-length Fracking

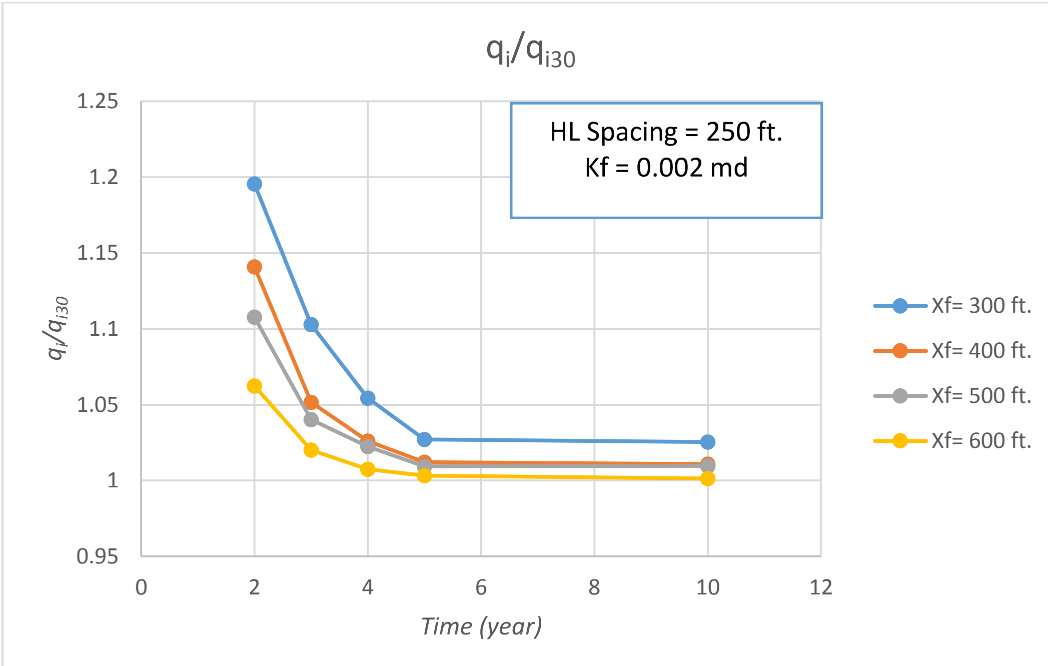


Table 4- 5: Arps DCA Constant Values for 13-Stages Model with Different Half-Length Fracking.

13 fracture Base Model						13 fracture Xf=400 ft Model				
years	n	di	qi	R^2		years	n	di	qi	R^2
2	2.073937	0.032448	9.355348	0.995208		2	2.437307	0.051567	9.392905	0.992359
3	1.435756	0.016453	8.783598	0.998043		3	1.655809	0.022051	8.657756	0.997705
4	1.261604	0.013878	8.635015	0.99799		4	1.439612	0.020214	8.447868	0.995529
5	1.182883	0.012136	8.523505	0.997593		5	1.335118	0.015178	8.331842	0.998066
10	1.155591	0.011905	8.52495	0.997483		10	1.30612	0.014877	8.322203	0.997959
30	1.13398	0.011724	8.444618	0.99762		30	1.231643	0.014615	8.232617	0.997091
13 fracture Xf=300 ft Model						13 fracture Xf=600 ft Model				
years	n	di	qi	R^2		years	n	di	qi	R^2
2	2.881988	0.100309	9.278224	0.986115		2	1.814091	0.015982	9.0897	0.994637
3	2.075912	0.049255	8.558907	0.993057		3	1.320869	0.010135	8.728845	0.995246
4	1.744365	0.03233	8.182156	0.996266		4	1.158203	0.008452	8.620209	0.993918
5	1.56603	0.025344	7.971017	0.997514		5	1.156631	0.008588	8.584365	0.994955
10	1.515201	0.02472	7.956567	0.997275		10	1.14383	0.008433	8.568451	0.995827
30	1.41217	0.020037	7.75984	0.998028		30	1.129622	0.008331	8.556288	0.996823

Now, the half-length of the fracking will be constant, but the permeability will be changed (0.004 md and 0.006 md). That will provide with values that needed to build the ratio graph between ${}^{n_t}/_{n_{30}}, {}^{d_{it}}/_{d_{i30}}$ *and* ${}^{q_{it}}/_{q_{i30}}$ vs Time. In figure 4-16, 4-17 and 4-18 shows the ratio graph between ${}^{n_t}/_{n_{30}}, {}^{d_{it}}/_{d_{i30}}$ *and* ${}^{q_{it}}/_{q_{i30}}$ and Time. While in Table 4- 3 shows the Constants values of each different scenarios in seven frack stages model of which the graphs in figure 4-16, 4-17 and 4-18 were used to build.

Figure 4- 16: Ratio of ${}^{n_t}/_{n_{30}}$ vs Time for 13-Stages Fracks with Different Fracking Permeability

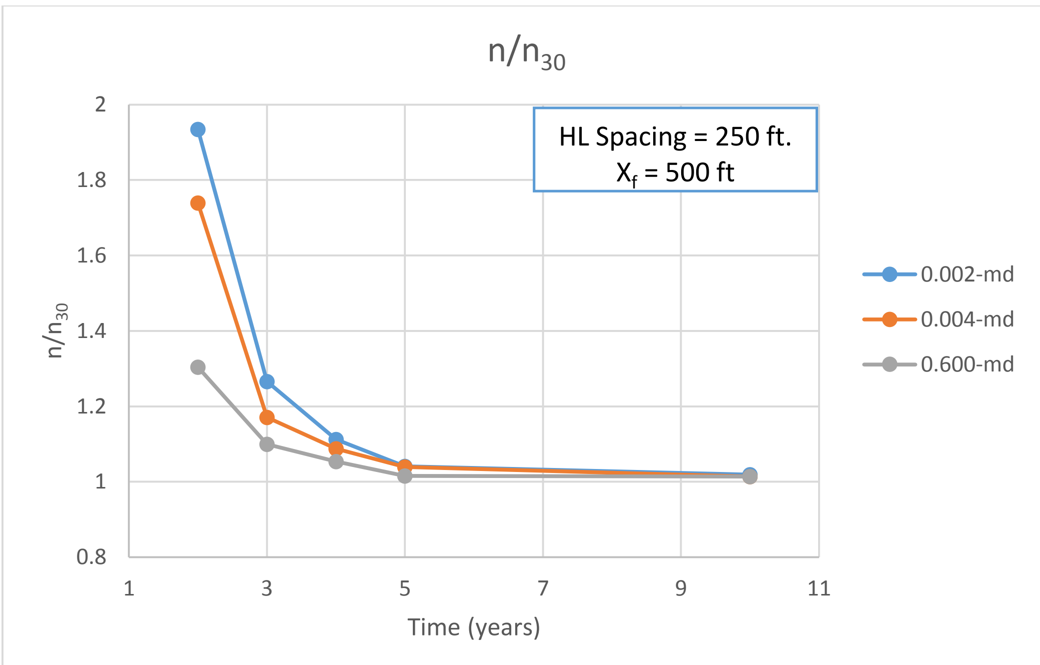


Figure 4- 17: Ratio of $^{di_t}/_{di_{30}}$ vs Time for 13-Stages Fracks with Different Fracking Permeability

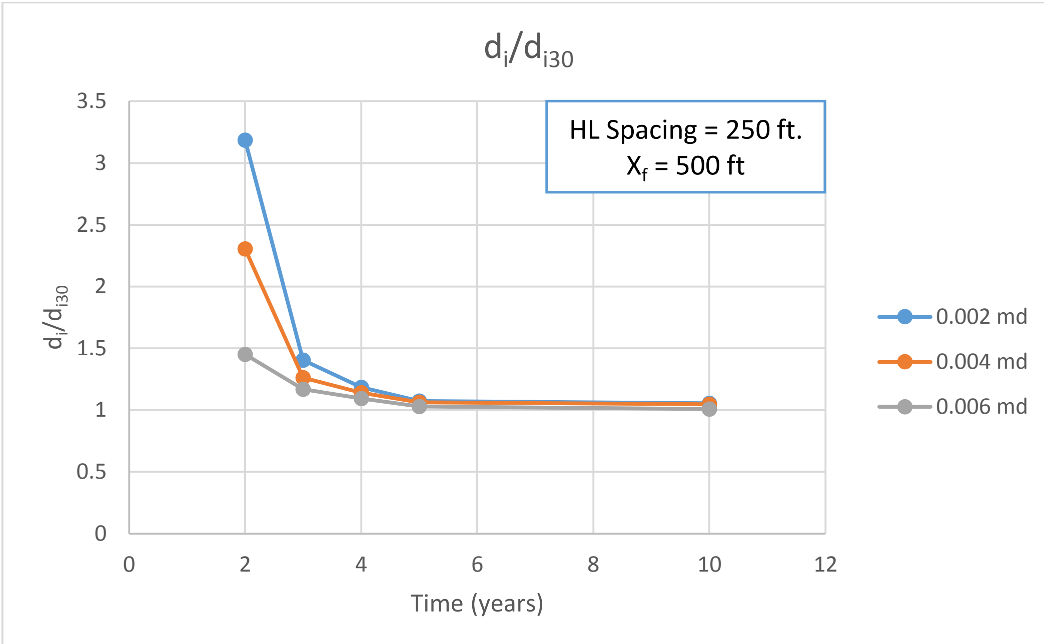


Figure 4- 18: Ratio of $^{q_{it}}/_{q_{i30}}$ vs Time for 13-Stages Fracks with Different Fracking Permeability.

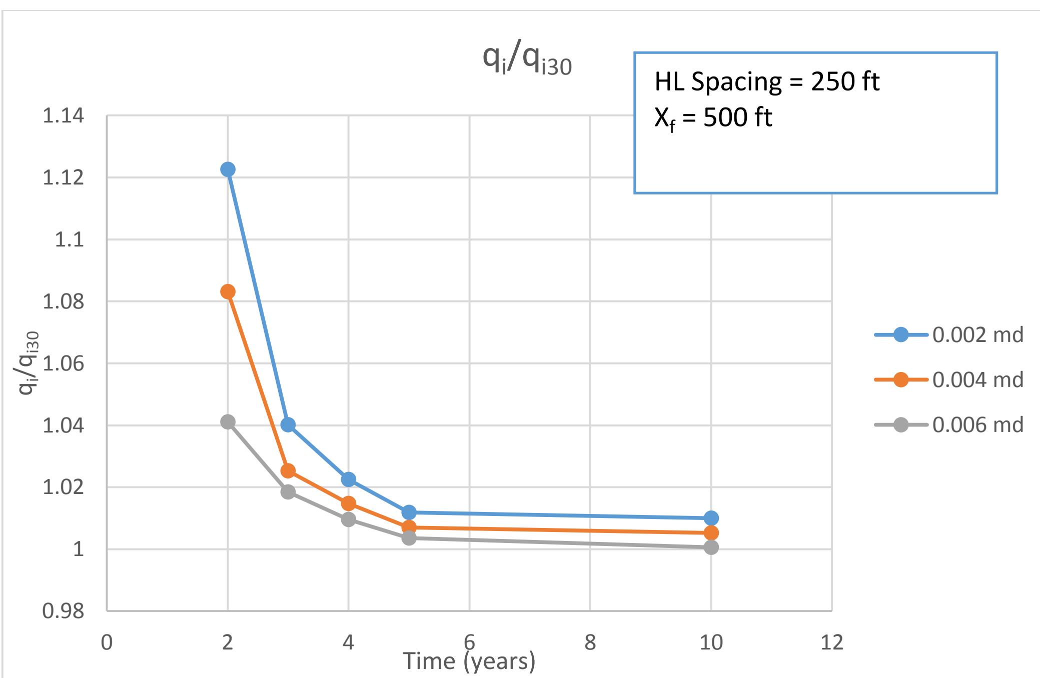


Table 4- 6: Arps DCA Constant Values for 13-Stages Model with Different Fracking Permeability.

13 fracture Base Model				
years	n	di	qi	R^2
2	2.073937	0.032448	9.355348	0.995208
3	1.435756	0.016453	8.783598	0.998043
4	1.261604	0.013878	8.635015	0.99799
5	1.182883	0.012136	8.523505	0.997593
10	1.155591	0.011905	8.52495	0.997483
30	1.13398	0.011724	8.444618	0.99762

13 fracture K= 0.006 md Model				
years	n	di	qi	R^2
2	1.228906	0.013085	10.94344	0.99909
3	1.035989	0.010533	10.70616	0.998591
4	0.993171	0.00986	10.61227	0.998179
5	0.956793	0.009282	10.55001	0.997611
10	0.955289	0.0091	10.51823	0.997373
30	0.942157	0.009016	10.51172	0.997302

13 fracture K= 0.004 md Model				
years	n	di	qi	R^2
2	1.769461	0.023208	10.58832	0.996204
3	1.191241	0.012696	10.02309	0.99879
4	1.106969	0.011482	9.920237	0.998674
5	1.05696	0.010703	9.844378	0.998441
10	1.031574	0.010542	9.826905	0.99831
30	1.01737	0.010066	9.77598	0.998117

4.4 Case Study For Confirming the Accuracy of Arps DCA.

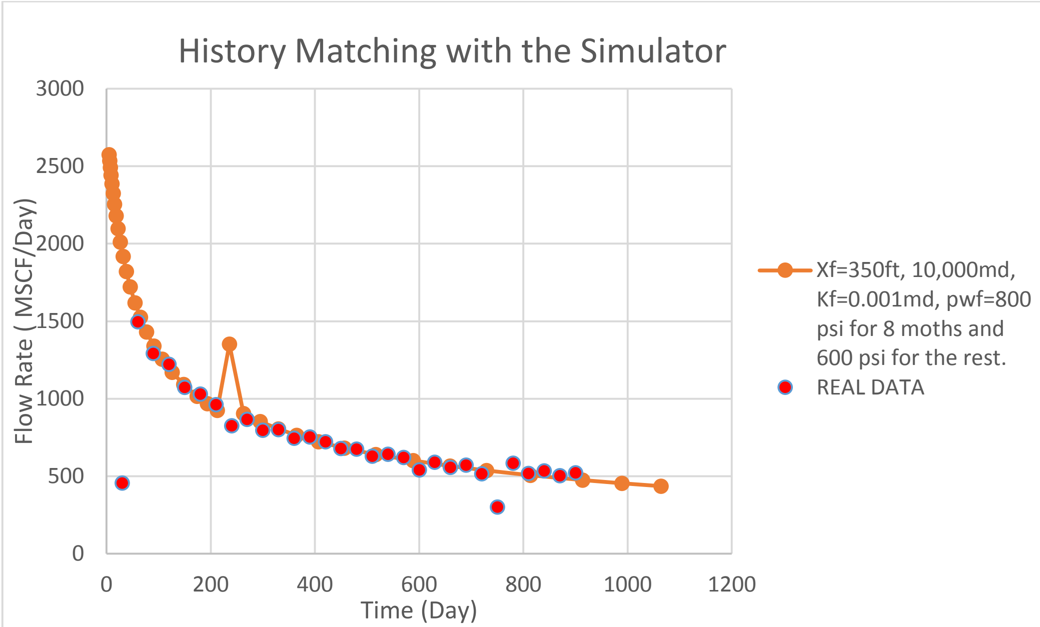
After making the theory and building the figures, now Arps DCA should work on other wells and other scenarios that look like or similar to the models we have built before. This time, we have a well that has been produced from for 2.5 years and fracked five times with separation of 350 ft. and half-length of 350 ft. (Parameters in table 4-7).

Table 4- 7: Real Data Well Parameters That Has Been Producing for 2.5 Years.

Real Data Well of 2.5 Year of Production	
Reservoir Parameters	
Layer Name	Marcellus
Formation Thickness, ft.	75
Reservoir Length, ft.	3,624
Reservoir Width, ft.	1,812
Horizontal Well. Ft.	2,000
Initial Reservoire pressure, psia	3,000
Gas Saturation, frac.	0.85
Fissure Porosity, frac.	0.005
Matrix Porosity, frac.	0.05
Fissure perm, i, j and k, md	0.001, 0.001, 0.0001
Matrix perm, i, j and k, md	0.0004, 0.0004, 0.00004
Fissure Spacing, σ, 1/ft^2	0.0073
Hydrulic Fracture Propeties	
Halt-Length, ft.	350
Width, in.	0.01
Top of Fracture, ft.	7000
Bottom of Fracture, ft.	7075
X center, ft.	500
Y cetner, ft.	1000
Permeability, md	10,000
Porosity, frac.	0.2
Nmber of Fracture Stages	5
Well Production Controls	
P_wf psia	800 psi first 8 months
	600 psi to 2.5 years
Adsorption	
Diffusion Coefficient, ft^2/day	1
Sorption Time, day	62
Longmuir Pressure, psia	635
Longmuir Concentration, MSCF/ton	0.09

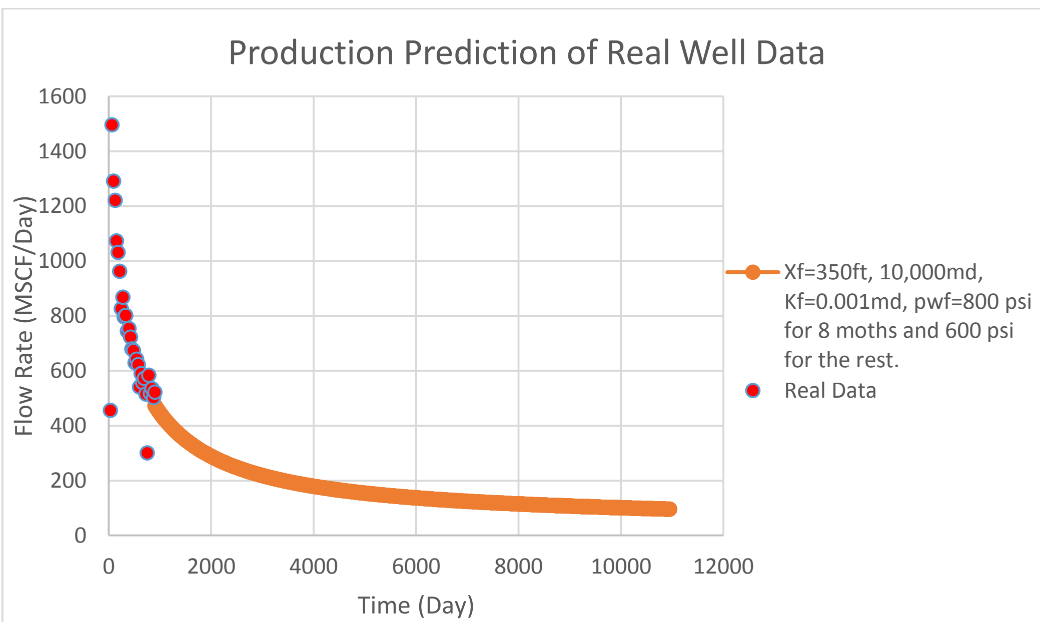
First, the constant of Arps DCA should be found at 2.5 years for this case. To find that, building a simulation model on Eclipse should be built. This model should be matching the actual real data. Figure 4-19. Next step is finding the constant values of Arps DCA by using the simulation model that has been built

Figure 4- 19: History Matching Between the Real Data and Simulation Model.



Since the simulation and the real life data are matched then this simulation mode will be used to predict the production to thirty years of production Figure 4-20.

Figure 4- 20: Real Well Production Prediction Using Simulation Model.



Next step is finding the constant values of Arps DCA by using the simulation model that has been built. In Table 4-8 shows the constant values of Arps DCA that will match the Real Data.

Table 4- 8: Constant Values of Arps DCA in 2.5 years That Matching the Real Data Values.

the Arps Constant for 2.5 years						
n	d_i	q_i	R^2	avg q	S_{SE}	S_{ST}
2.845356	0.04164	3082.091	0.984232	1601.995	511735.6	32454240
time(days	(MSCF/Da	q_t'	$(q_t-q_t')^2$	$(q_t-q)^2$		
0.999316	3154.85	2963.234	36716.51	2411358		
1.498973	2897.903	2910.002	146.3901	1679377		

After finding out the constant Values, the values of $^{n_{2.5}}/_{n_{30}}, ^{d_{i2.5}}/_{d_{i30}}$ and $^{q_{i2.5}}/_{q_{i30}}$ should be found from the graphs that has been built before. Since the half-length is 350 ft, the $^{n_{2.5}}/_{n_{30}}, ^{d_{i2.5}}/_{d_{i30}}$ and $^{q_{i2.5}}/_{q_{i30}}$ should be chosen by using what is equivalent to 350 ft. half-length frack from seven stage frack models figure 4-7, 4-8 and 4-9. The resone that the seven stages was picked and not the thirteen stages is because the separation distant between each frack is 400 ft. which is closer to the seven stages scenario than thirteen stages.

Table 4- 9: The values of $^{n_{2.5}}/_{n_{30}}, ^{d_{i2.5}}/_{d_{i30}}$ and $^{q_{i2.5}}/_{q_{i30}}$ Using 300ft Half-Length from 7and 13 –Stages Fracking.

Half Length= 350 ft & 2.5 years	
	7 stages
n/n30	1.984963439
di/di30	13.85195786
qi/qi30	1.370115689

Last the $^{n_{2.5}}/_{n_{30}}, ^{d_{i2.5}}/_{d_{i30}}$ and $^{q_{i2.5}}/_{q_{i30}}$ will be used to find n_{30}, d_{i30} and q_{i30} from seven stages. Then the constant that will be calculated at 2.5 years will be used and modified to confirm the study results. In Table 4-10 shows the constant of Arps DCA using seven stages $^{n_{2.5}}/_{n_{30}}, ^{d_{i2.5}}/_{d_{i30}}$ and $^{q_{i2.5}}/_{q_{i30}}$

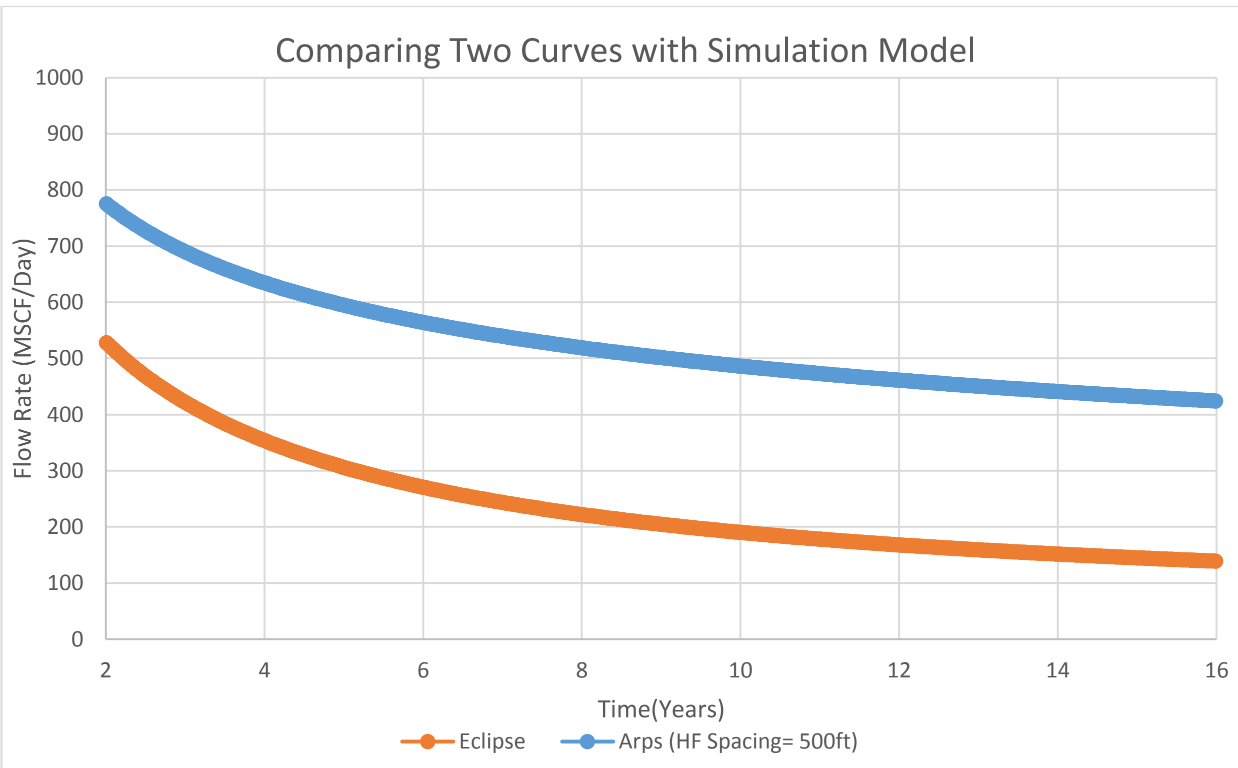
Table 4- 10: Constant Values and Regression Coefficient that found from 7-Stage Graphs

n	d_i	q_i	R^2	avg q	S_{SE}	S_{ST}
3.442238	0.269459	5159.654	0.86113	264.2024	20588419	1.48E+08

time(days	(MSCF/Da	q_t'	$(q_t-q_t')^2$	$(q_t-q)^2$
0.999316	3154.85	4264.48	1231280	8355843
1.498973	2897.903	4005.657	1227119	6936378

and to compare the prediction production between Arps and the simulator, Figure 4- 21 show the prediction from 2.5 years until 15 years from the age of the well.

Figure 4-21: Comparing Arps DCA with Simulation Model



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5 Conclusion

The following conclusion can be noted in this study.

1. The production profile of Marcellus shale well can be closely fitted to Arps DCA.
2. Curves For n_t/n_{30}, d_{it}/d_{i30} and q_{it}/q_{i30} could be defined and used to find n_{30}, d_{i30} and q_{i30} after a short limited production time to get a good constant values that will give more accurate production prediction.
3. A number of correlation were developed to adjust the Arps DCA constants obtained from limited production history to achieve more accurate production prediction.
4. The Application of the methodology developed in this study to field data confirmed that accurate prediction production can be achieved.

6 Reference

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