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Identifying Infill Locations and Underperformer Wells in Mature Fields using Monthly Production Rate Data, Carthage Field, Cotton Valley Formation, Texas

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Abstract

Recent increase in global demand for energy and the consequent high prices have prompted a need for improving the recovery from mature reservoirs. Identifying sweet spots in these fields for in-fill drilling and ranking the infill locations based on their potential productivity as well as underperformer wells as candidates for remedial operations are important for improving the economics of mature fields.

One of the most important issues that make analysis of mature fields quite challenging is lack of data. Production rate data is about the only data that can be easily accessed for most of the mature fields. The most accessible production data usually does not include flowing bottom-hole or well head pressure data. Lack of pressure data seriously challenges the use of conventional production data analysis techniques for most of the mature fields. The motivation behind development of the techniques that are presented in this study is to demonstrate that much can be done with only monthly production rate data in order to help the revitalization of mature fields.

Methods currently used for production data analysis are decline curve analysis, type curve matching, and history matching using numerical reservoir simulators. Each one of these methods has its strengths and weaknesses. They include significant amount of subjectivity when they are used individually in the context of production data analysis.

In this paper, intelligent systems are used in order to iteratively integrate the abovementioned techniques into one comprehensive methodology for identification of infill drilling locations as well as underperformer wells that would be the prime candidates for restimulation and/or workovers. Application of this technique to a large number of wells in the Carthage field, Cotton Valley formation is presented.

Intoroduction

Several production analysis tools and strategies for estimating the remaining reserve, identifying infill drilling locations and underperformer wells exist in the oil and gas industry. In order to make any conclusions using most of these methods, a large amount of data such as production data and reservoir properties are required.

Production data analysis techniques have improved significantly over the past several years. These techniques provide the engineer some of the reservoir properties and estimates of the hydrocarbon in place and ultimate recovery. First and most common method for production data analysis is decline curve analysis.

Decline Curve Analysis (DCA) is a method to fit the observed production rates of individual wells, group of wells, or reservoirs by a mathematical function in order to predict the performance of the future production by extrapolating the fitted decline curve. DCA was first introduced by Arps [1] in 1940s using mathematical equations. The reason for DCA being widely used is its simplicity and since it is an empirical method, it does not require any information regarding the reservoir or well parameters. The mathematical functions are characterized by three parameters; q_i (initial flow rate), b (decline exponent), and D_i (initial decline rate.) When $b = 0$, the decline is exponential. When $b = 1$, then the decline is harmonic. When $0 < b < 1$, the decline is hyperbolic.

Fetkovich [2] introduced decline curve analysis by type curves in 1980s by relating Arps' decline parameters to some reservoir engineering parameters for production against constant bottom-hole pressures. Over the past few years, the type curve matching methods have been improved by several people in order for them to be used for different reservoir types and producing scenarios.

Although decline curve analysis and type curve matching techniques are still being used widely, but the results they provide are highly subjective.

Reservoir history matching is also used in the oil and gas industry mostly in major companies. Performing history matching for a reservoir is a time consuming process and it requires a large amount of data such as reservoir properties, production and pressure data, and well parameters. Lack of any of these data will result in poor conclusions about the reservoir.

The technique presented in this paper integrates the three abovementioned techniques (decline curve analysis, type-curve matching, and single-well production history matching) through an iterative process in order to remove the subjectivity of each these methods if they are performed individually and to come up with a set of representative reservoir properties. In addition, intelligent techniques such as fuzzy pattern recognition, neural networks and fuzzy logic in order to make decisions on identifying locations for infill drilling and underperformer wells. Actual production data from Carthage field, cotton valley formation are used in this analysis.

Methodology

In this section, the procedure for intelligent production data analysis (IPDA) is introduced. The reader should keep in mind that IPDA is developed for the situations that only production data are available. In cases that other information is available such as geologic data, pressure tests, core analysis, and etc., one might choose to use other well established techniques [3].

Nevertheless, as more data such as those mentioned above are available, one may use them to increase the accuracy and the reliability of the methodology being introduced here.

IPDA has two major components. The first component is an iterative process, which decline curve analysis, type curve matching and history matching, are performed on the production data of a particular well in the field until convergence is achieved to a unified set of reservoir properties. Given the fact that each of these techniques are quite subjective by nature, by letting each one technique to guide and keep an eye on the other two during the analysis, the degree of confidence and reliability on the results as well as repeatability of the analysis will increase.

The second component (fuzzy pattern recognition) is intended to integrate the abovementioned information in the context of the entire field to illustrate the field's status at any time in the future in order to identify the underperformer wells and locations for infill drilling.

The first step is decline curve analysis, which the production rate and cumulative production data are plotted against time on a semi-log scale and a decline curve is fitted. An automatic optimization routine finds the best decline curve for the given well, as both the rate and cumulative versus time are simultaneously matched. Figure 1 shows an example of decline curve analysis for a well in Carthage field, Cotton Valley. If one uses hyperbolic decline, then the results of the decline curve analysis would be a set of q_i, b and D_i. Once the matching process is completed and the three parameters have been identified, you can calculate Estimated Ultimate Recovery (EUR) for a certain number of years for the selected well. In this analysis EUR is calculated for 30 years. The 30 year EUR for the well shown on figure 1 is calculated to be 3,679 MMSCF.

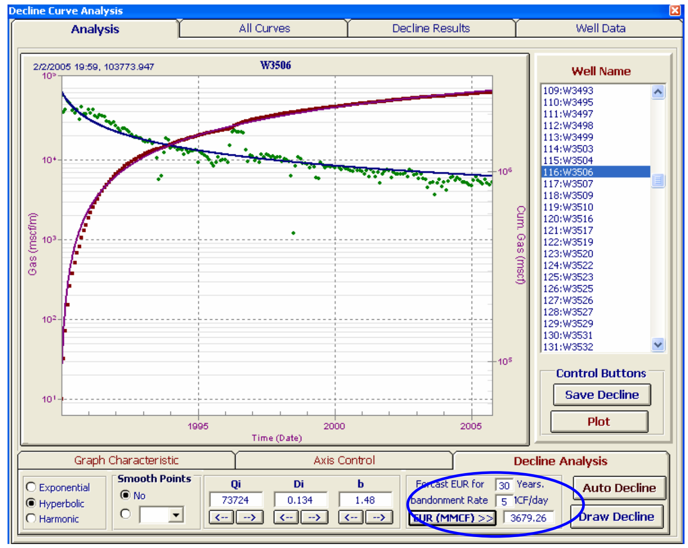

Figure 1 is an example of decline curve analysis for well W3506.

The second step in this process is type curve matching where based on the b value obtained from the first step, a set of type curves will be generated. These type curves are developed by Cox [4] for low permeability gas reservoirs for production rate data not pressure. Figure 2 shows an example of type curve matching for the same well shown on figure 1 using the actual production data.

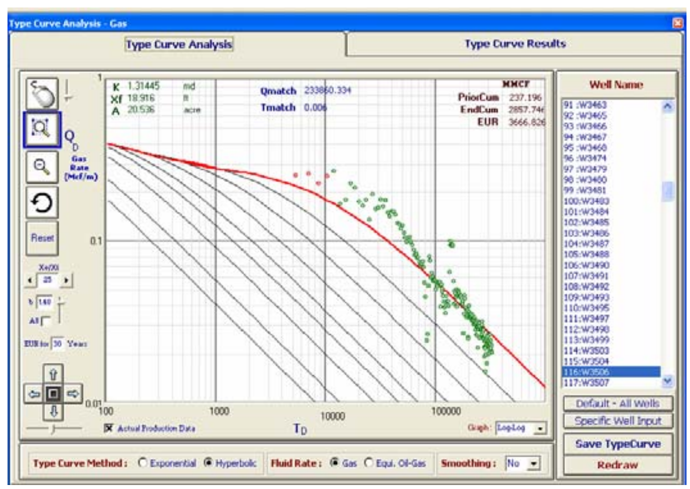

Figure 2 is an example of type curve matching for well W3506.

In situations that the actual production data are very scattered and a good match cannot be obtained, one may use the data of the fitted decline from decline curve analysis as it is shown on figure 3.

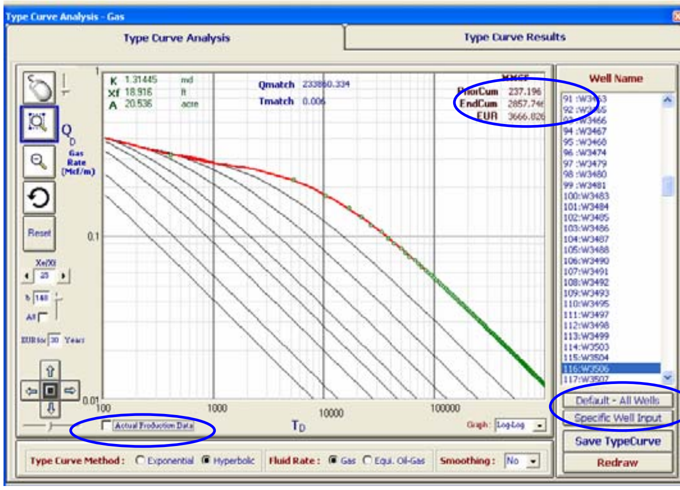

Figure 3 shows the type curve matching using fitted decline curve data.

In this step, a good match is acceptable if the 30 year EUR calculated here is in a reasonable range with the one calculated from decline curve analysis. The EUR value could be considered as a controlling parameter that holds the integrity of these methods together. This value will also be checked when history matching is performed. In this example, the EUR calculated from type curve matching is 3,666 MSCF which is very close to 3,679 MSCF calculated from decline curve analysis. The outcome of history matching process is a set of reservoir properties such as permeability, fracture half length, and drainage area. The type curve matching requires knowledge about a set of reservoir parameters. These parameters are used to calculate permeability, fracture half length, drainage area and EUR. These parameters are:

- o Initial reservoir pressure,
- o Average reservoir temperature,
- o Gas specific gravity,
- o Isotropicity (k_x / k_y ratio),
- o Drainage shape factor (L/W ratio),
- o Average porosity,
- o Average pay thickness
- o Average gas saturation, and
- o Average flowing bottom-hole pressure.

Most of these parameters can be (and usually are) guessed within a particular range that is acceptable for a particular field. The values of some of these properties were selected to be in a close range with the actual data found in the literature [5, 6, 7]. These data were used as default for the entire reservoir.

If during the type curve matching process, a good match between the two EURs calculated from decline curve analysis and type curve matching is not obtained, we should return to decline curve analysis and try to get a match with a different value of b and by having this new value of b , we will repeat the type curve matching process. This procedure should be repeated until an agreement between the two calculated EURs is obtained.

The third step is production history matching using a single-well reservoir simulator. Reservoir properties that were the results of type curve matching are used as the starting point for history matching and the objective is to match the production data of a particular well. History matching is not a simple and straight forward procedure. One of the important tasks in history matching is to match the reservoir pressure. But what would we do if we don't have the reservoir pressure data? The answer to this question could be that we will continue matching only the production data (if that's the only data we have) and try to come up with a set of reservoir properties that make physical sense.

Many times the results of history matching will force us to go back to decline curve analysis and type curve matching and reevaluate our decline curve results and type curve match. This rigorous iterative process is the key to the successful completion of this process. Again, the 30 year EUR is a controlling point that the value we get in history matching should be in a reasonable range with the one calculated from decline curve analysis and type curve matching.

Once the match is obtained, the ground work has been established for another important step in this analysis, namely Monte Carlo Simulation. Since most probably we have diverged from the reservoir characteristics that we started the history matching with, it is reasonable to expect that we have converged on a range of values for each of the parameters rather than a single value. Monte Carlo Simulation is a good way to get a more realistic look at the capabilities of a well and its potential future production.

The result of the Monte Carlo Simulation is the 30 year EUR in the form of a probability distribution. If our analysis for a particular well has been done properly, the values of EUR calculated from decline curve analysis and history matching should fall within the probability distribution that has been calculated from Monte Carlo Simulation. As the values of these EURs get closer to the higher probable values, our confidence on the accuracy of the ranges (of the reservoir characteristics) that were used in the Monte Carlo Simulation will increase. Figures 4 and 5 show the results of history matching and Monte Carlo Simulation for a well in Carthage field.

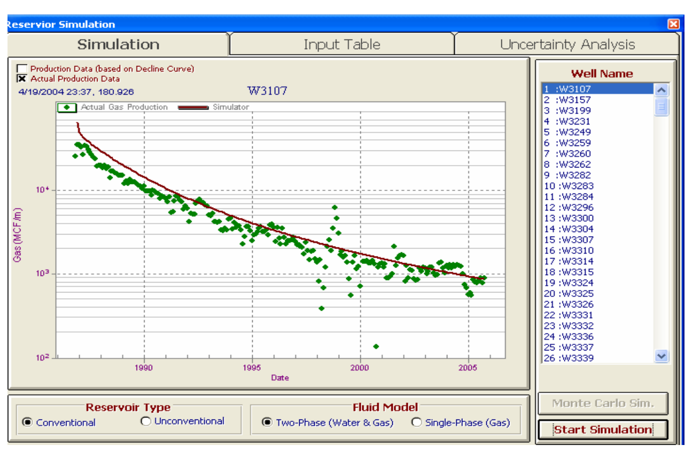

Figure 4 shows the results of history matching for well W3107.

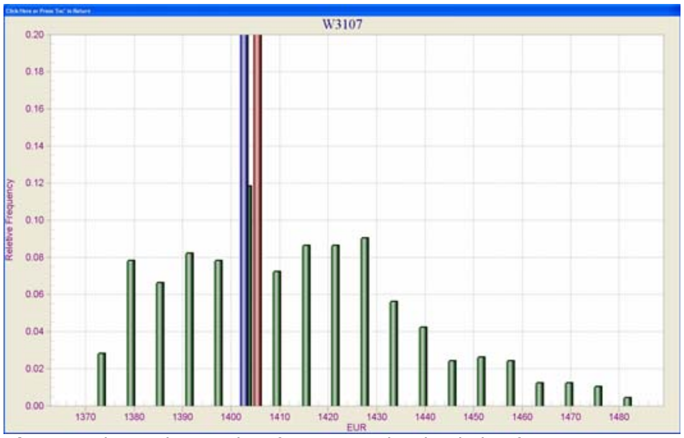

Figure 5 shows the results of Monte Carlo Simulation for W3107.

Once the individual analysis for all the wells in the field is completed, the following information for all the wells in the field is available: initial flow rate, q_i, initial decline rate, D_i, hyperbolic decline, b, permeability, k, drainage area, A, fracture half length, X_f, and 30 year Estimated Ultimate Recovery, EUR.

Production indicators (PI) are calculated for each well. These PIs offer a measure of the well's production capability, which can be used for comparison with the offset wells. The PIs that are automatically calculated for each well are the best 3, 6, 9, and 12 months of production, first 3, 6, 9, and 12 months of production, three year cumulative production, five year cumulative production, ten year cumulative production, and current cumulative production [8]. Additional PIs can also be included from decline curve analysis and type curve matching. The reservoir can be partitioned based on each one of these PIs and the Relative Reservoir Quality Index (RRQI) values are generated.

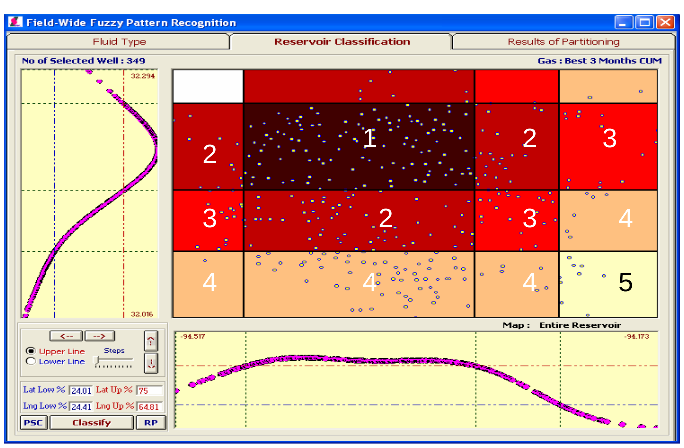

Figure 6 shows the RRQI based on best 3 months of production.

As an example, figure 6 shows a two-dimensional map of 349 wells in the Carthage field that have been partitioned based on the best 3 months of production. The numbers on the map indicate the RRQI values with RRQI 1 (the darkest color) being the highest quality. These maps will help the engineer to identify the sweet spots as the best locations for in-fill drilling and also by super imposing different maps, identifying the underperformer wells.

The identification of underperformer wells in IPDA is a multi-level analysis. Each level includes the involvement of two production indicators. In this analysis, "first 3 months of production" and "first 3 years of production" are used as the production indicators for level one. In order for a well to be considered as an underperformer, two conditions must be met:

1. Its value for the particular PI that is being analyzed must be in the bottom 25% of the PI values of all the wells that belong to the same RRQI.
2. Its PI value must be lower than the average PI value of all the wells that belong to the next RRQI (lower quality portion of the reservoir.)

Results and Discussion

The methodology described in this paper was applied to production data from 349 wells production in Carthage field Cotton Valley formation in Texas. The only data used to perform the analysis described here was the production data that is publicly available.

The first step in the process is performing decline curve analysis, type curve matching and history matching using a single-well radial reservoir simulator on all the wells in the field. These techniques are performed simultaneously in an iterative process until convergence to one unified set of reservoir characteristics and EURs is obtained for each individual well while keeping the integrity of the whole reservoir as one system. Figure 8 shows the results of decline curve analysis, type curve matching and history matching on well W3483 in Carthage field. The EURs from these three methods are calculated to be 1233, 1235 and 1224 MMSCF, which are reasonably close to one another. Figure 7 shows the results of Monte Carlo Simulation on W3483.

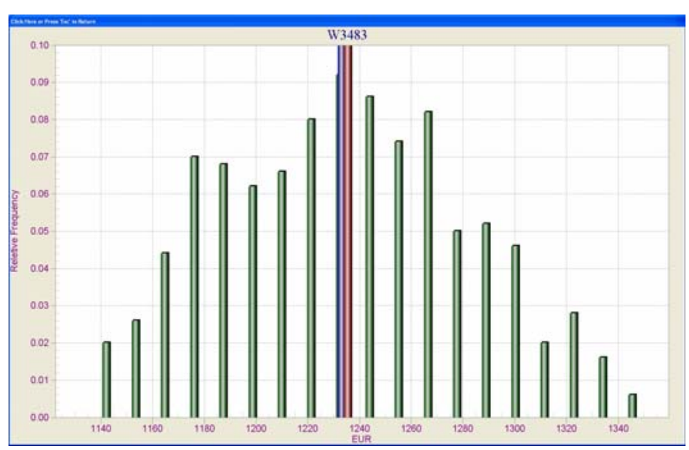

Figure 7 shows the results of Monte Carlo Simulation on W3483.

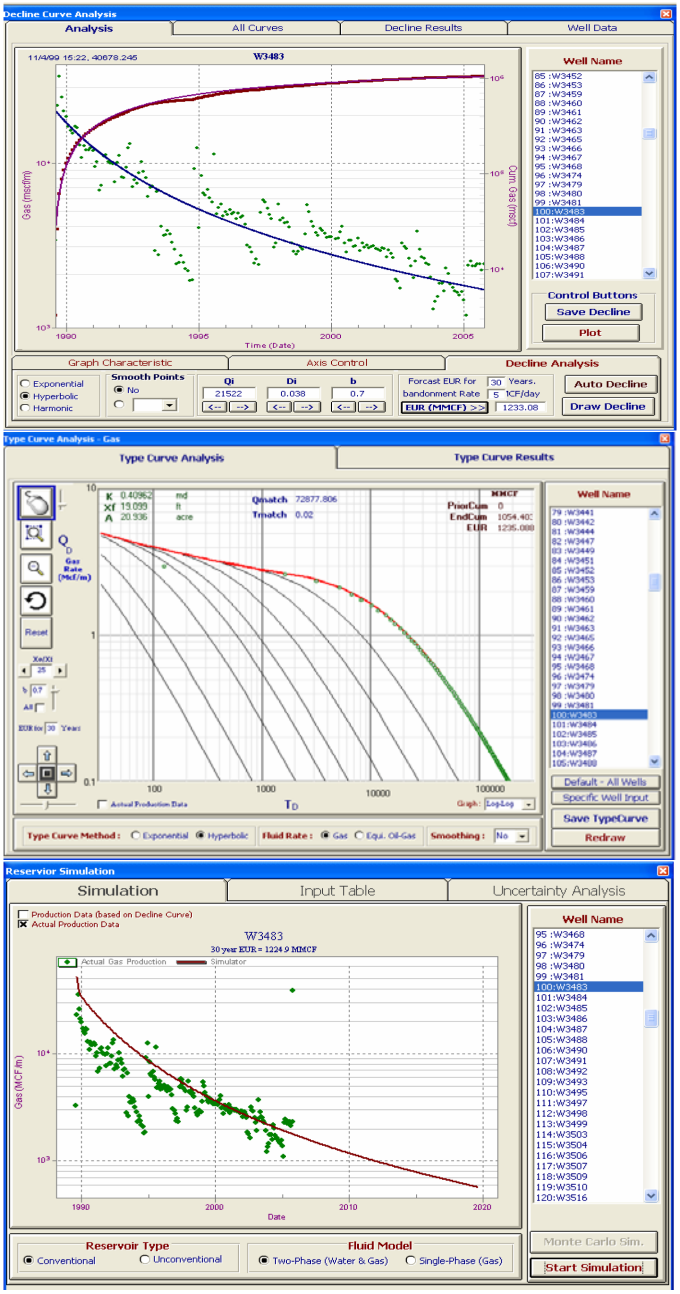

Figure 8 shows the decline curve analysis, type curve matching and history matching on well W3403

Figures 9 and 10 show the field partitioning based on the first 3 months and first 3 years of production. Notice the selected wells on the western part of the field have been moved from one partition (RRQI 1) to another (RRQI 2.) This could indicate the relative reservoir depletion throughout time.

Figure 11 shows the partitioning of the reservoir based on the last month's production of the field. Comparing the fuzzy pattern recognition curves along with the latitude and longitude, one may notice significant changes between figures 9 and 10 when compared to that of figure 11. It is obvious that the sweet spot (partition with RRQI 1) has moved to the northern part of the field.

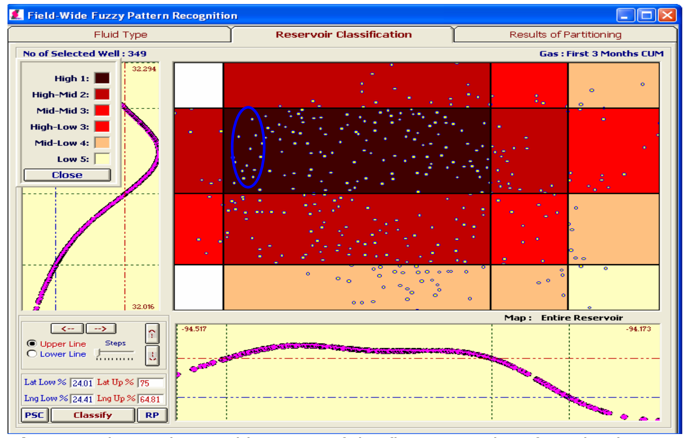

Figure 9 shows the partition map of the first 3 months of production.

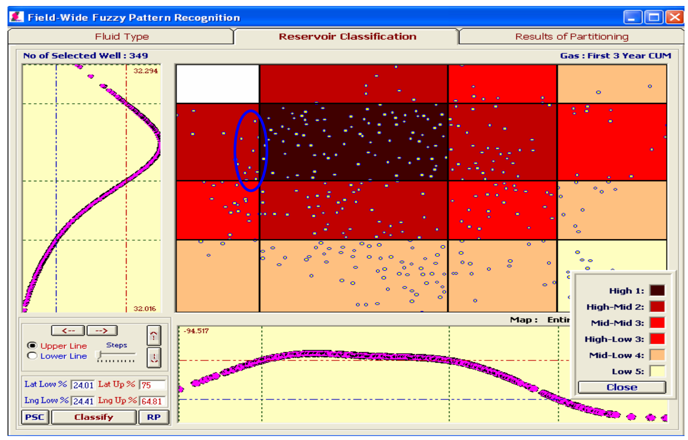

Figure 10 shows the partition map of the first 3 years of production.

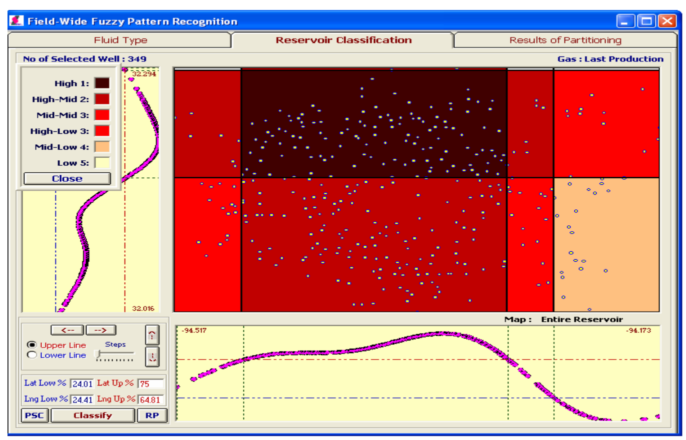

Figure 11 shows the partition map for the last month of production.

Figure 12 shows the partitioning map of the field based on permeability. The underperformer wells are identified based on the rules described in the methodology. These wells are shown in blue.

Figure 13 shows the three dimensional view of drainage area, fracture half length and permeability patterns in Carthage field, Cotton Valley formation in Texas. The patterns show the high permeability zones are located in the north western part of the field. The drainage area map shows higher values of drainage areas in the midsection towards north western part of the field. Also, the midsection towards north western part of the field has higher values of fracture half length.

Managers, engineers and geologists would be able to use these maps to make strategic decisions for development of the field, such as identifying the sweet spots for infill drilling.

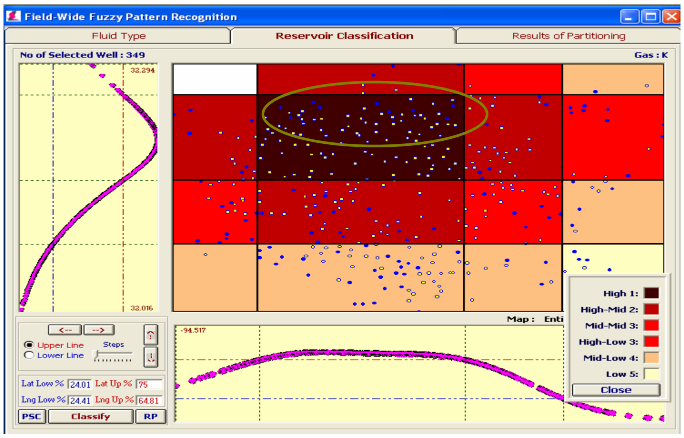

Figure 12 shows the partitioning map of the field based on permeability. The underperformer wells are shown in blue.

Conclusions

The technique presented in this paper integrates the three production data analysis techniques (decline curve analysis, type-curve matching, and single-well numerical reservoir simulation for history matching) through an iterative process in order to remove the subjectivity of each of these methods to come up with a set of representative reservoir characteristics. In addition, intelligent techniques such as fuzzy pattern recognition are used in order to make decisions on identifying locations for infill drilling and underperformer wells.

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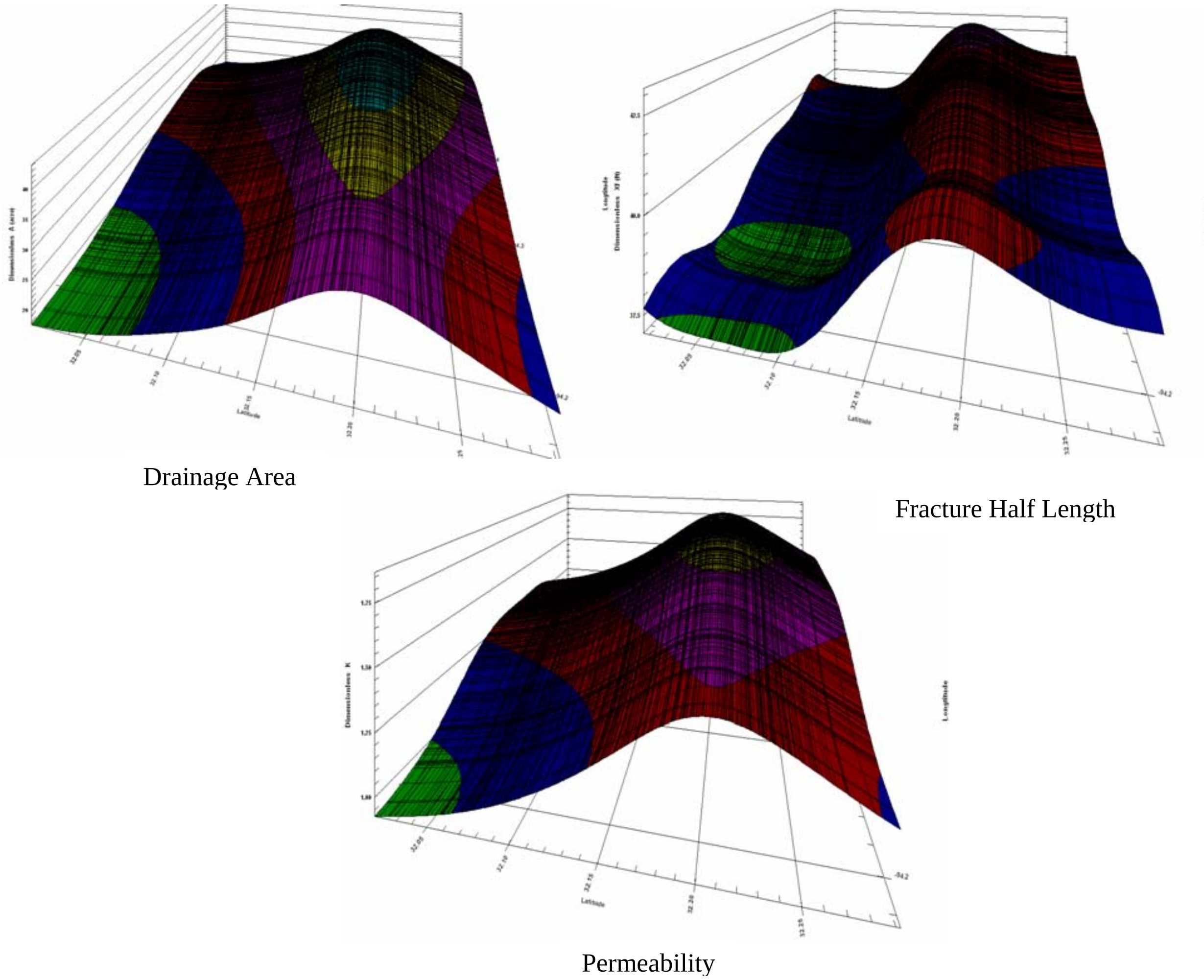

Figure 13 shows the partitioning maps of drainage area, fracture half length and permeability for the entire reservoir.