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Fracture Optimization eXpert (FOX) - How Computational Intelligence Helps the Bottom-Line in Gas Storage; A Case Study

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ABSTRACT

Just like any other industry, the bottom-line in gas storage is economics. Any tool, new or old, conventional or unconventional, is evaluated by its contribution to the bottom-line. Fracture Optimization eXpert (FOX) is a new software tool that has been developed using the cutting edge of information technology, namely Computational Intelligence. Two different paradigms of Computational Intelligence was used in development of FOX. They are Artificial Neural Networks and Genetic Programming.

What distinguishes FOX from conventional frac simulators (Frac-pro, ...) is its unique capability to A) not only predict post-frac deliverability but also B) suggest the best possible combination of frac parameters for optimum results. Furthermore, FOX is able to do this using only historical (production / injection) data and well completion data. In other words, FOX can do without reservoir data such as porosity, permeability, and stress profile data that are an essential part of any conventional approach.

In this paper FOX is applied to a gas storage field in north eastern Ohio (Clinton Sand). The accuracy of its post-frac deliverability prediction is demonstrated. Using only available historical data optimum frac jobs are designed and the improvement of post-frac deliverability is calculated. A cost - benefit analysis is performed to show the advantages of using this method when compared to conventional approach.

FOX can help the bottom-line by eliminating the need for expensive data collection processes such as well tests, coring,...., while its predictions of post-frac deliverability has a high accuracy. Furthermore, even if such data is available for a field, conventional frac simulators only provide frac job outcome for any particular design, planned by engineers. They are not able to optimize the frac treatment procedure to get the best possible result for any individual well, a capability that makes FOX unique.

INTRODUCTION

Details about FOX has been covered in previous SPE papers[1-3]. In this paper an economical evaluation will be presented to show the benefits of using such a tool. It has been brought to our attention that in today's corporate environment, showing the results and scientifically proving their accuracy and applicability may or may not be sufficient. Demonstrating the capability of the new and novel tools in cost cutting measures and increasing revenues sometime becomes essential. This is specially true in gas storage industry where many of the financial calculations may not be straight forward and the advantages brought about are not quite obvious. In this paper authors will attempt to show the economic advantages that tools like FOX will realize. These economic advantages are two folds. First is the cost savings due to eliminating the need to do more well test, core extraction and analysis, and ...

Please note that these all are necessary if and only if the company in question would like to incorporate the petroleum engineering technology that has been developed over many years. This technology includes state-of-the-art hydraulic fracture simulators that reduce the guess work involved in such operations to a minimum. There are operations that do not see any need for such elaborate testings or any kind of simulations and scientific design. They do things the way that they have done for many years and are quite comfortable with it. Such operations do not realize that there are actually tools out there that can improve the outcome.

FOX can also have financial advantages by decreasing the hydraulic fracture failure rate considerably. Simply by being able to estimate or predict the outcome of a frac job prior to its actual implementation, those wells that are not going to provide a satisfactory post-frac deliverability will not be treated.

Instead, other wells which would not have been treated but would have given good results will be treated due to FOX's prediction of a successful frac job. Another way that FOX will have financial advantages is by optimizing even the successful frac jobs. FOX is able to enhance frac job outcomes by an average of 30% over the conventional ways of frac designs. Following section provides a brief overview on how FOX does all this.

HOW DOES FOX WORK

Fracture Optimization eXpert (FOX) is the result of almost four years of research and development performed at Petroleum and Natural gas Engineering department, West Virginia University. More than being a software application that can now be used for a gas storage field in Ohio, FOX is a concept and a methodology. Due to its modular development, it can be applied to any type of field or operation.

FOX has two major component. First is the predictor and second is the optimizer. In its present format for the field in Ohio, the predictor module accepts input parameters such as individual well information, including production history and proposed frac design and predicts the post-frac deliverability. The backbone of this component is an artificial neural network. This network has been trained using the historical data available on this field. This network has shown to be quite accurate for this field. Figure 1 shows the network accuracy compared to the data that was used for its training. Figure 2 shows the network accuracy on new data. This data was not shown to the network during training. This figure shows the predictive capability of this module.

The question is, how is it that a neural network can do what conventional tools can't. For a conventional tool, i.e. a frac simulator, to be able to do this, engineers need to have a suite of reservoir data such as porosity, permeability, thickness and stress profiles. Yet a neural network can do without these information. The answer is that neural networks have a unique capability of extracting implicit information that is embedded in the data. For instance, all the reservoir information needed for a conventional analysis is embedded in the production history. In other words, production history of a well carries the signature of the reservoir properties. Just because we don't have the analytical tools to extract them does not mean they are not there. Aren't these reservoir properties responsible for a well to produce in a certain manner? Show certain transient characteristic?, And specific pseudo-steady state or boundary dominated characteristics? They are. Next come the problem of uniqueness. It is possible for two wells with different combinations of reservoir features to display similar production characteristics. One should provide the network with enough information on an individual well (beside the production history) to give that well as unique qualities as possible. This is usually one of the challenges one will face during the development process. During a supervised training scheme the network is also provided with the result of each frac job. Given these information neural network tries to build an internal representation of the process behavior. It learns by observing this behavior. Neural network learns using many processing elements that are fully connected to one another, similar to synaptic connection within mammalian neural systems. This high degree of inter-connectivity, which provides high dimensionality, coupled with the fact that the information is being processed in a parallel and distributed fashion (as opposed to sequential and point-wise fashion that is done in conventional computing) gives neural networks a power unmatched by conventional methods. Above all, results speak for themselves.

The second module in FOX that is responsible for optimization of the frac design is developed using Genetic Algorithms[4]. Parameters governing the outcome of a frac job are numerous. FOX, in its present form, uses 17 different parameters. Range of variability of each parameter is different. Some parameters have much wider ranges than others. Theoretically, there should be certain combinations in the ranges of these parameters that result in best possible frac outcome. The problem is that the number of possible combinations of these parameters turns out to be astronomical. For example, in the field in Ohio this number was approximately 10^{21}. This number is referred to as the "search space". To put things in perspective it should be mentioned that, it would take about 300 million years to exhaustively search this space of all possible solutions, using a machine that can search one million possible combinations per second.

Genetic algorithms are adaptive, intelligent global search tools that are able to search large spaces of possible solutions quite efficiently. They use the Darwinian evolutionary principal of "survival of the fittest" to reach their goal. Generating a random population of possible solutions genetic algorithms apply them to a so called "fitness function". In our case the predictor module plays the role of the fitness function. The result is predictions of the outcome of those random initial population of the solutions. These results are ranked, and just like the natural evolution process, the highest ranking individuals will survive and reproduce. In this manner they pass on their "good"qualities (in the form of genes) to the next generation of solutions (design parameters). This newer generation is no longer random. They are the result of one generation of evolution. Continuing this process, eventually the most evolutionary (fittest) individuals will be developed. These are design parameters combinations with highest possible post-frac deliverability.

The two modules, the predictor, and the optimizer, work together in harmony, and complement each other. The outcome of the process is a customized and optimized frac design for every individual well.

ECONOMIC EVALUATIONS

From a market perspective, there are four salable components to a natural gas storage pool: the top gas capacity, the first-day deliverability, the last-day deliverability, and the peak-day deliverability. Once an storage pool is developed, and its design capacity and deliverabilities established, the future salability and viability of the pool is determined by the operator's success at maintaining design capacity/deliverability, and increasing capacity/deliverability.

Existing markets require that the operator maintain at least the minimum design capability of the pool. When the design capacities and/or deliverabilities fail, as they will over time, or when the operator wishes to expand a market for natural gas storage capacity/deliverability from existing pools, the operator seeks ways to restore or increase the design capacity/deliverability. One favored way is the hydraulic fracture or re-fracture of specific wells in the storage pool.

Whether the operator is seeking to maintain design cap/del, or seeking new cap/del, and chooses the hydraulic fracture, incremental cost is involved. This incremental cost requirement can be justified in only two ways: A) operating and maintenance cost as part of maintaining the design cap/del of the storage pool, or B) capital-budget dollars dedicated to service expansion.

When hydraulic fracturing is applied to one or a group of storage pool wells in order to maintain or recover design cap/del, the cost of the operation is an operation's cost, and is administered through the rate-design structure. The cost becomes either a rate-recoverable cost-of-service or an incremental cost recoverable through the storage-service customers. When hydraulic fracturing is applied to a well or a group of wells for the purpose of increasing cap/del beyond the original design parameters, the cost of doing so becomes a capital cost, and a component of the company's asset base for which it can earn a regulated rate-of-return. So the management, and recovery, of frac costs is not a simple concept.

Of particular interest to this paper is the concept, and operation, of designing an optimum hydraulic frac for a well, or a group of wells, in a natural gas storage pool in order to affect an increase in cap/del beyond the original storage pool design. The reason for this focus is to enhance the storage pool as a marketable commodity, presenting more capacity and more deliverability to the marketplace for sale as storage service.

Storage service, as described earlier, can be sold as capacity, or first, last or peak-day deliverability. Each, as a component of storage service, demands a different price as a commodity. When either storage pool capacity, or deliverability, is increased above the design capacity, or deliverability, of the storage pool, the increase is considered an "incremental" increase. So the gain in market value as the result of these increases are incremental gains. The understanding of this value concept is important to the understanding of the increased value possible in a storage pool operation due to hydraulic-fracture increases in cap/del, and the offsetting costs of the fracture work. Because the cost is an offset to whatever increase in incremental value (revenue) we see, the control of costs is crucial. Optimizing a fracture design (getting the maximum frac response for minimum dollars) is crucial to this strategy.

The increase in market value of the storage pool commodity is based on incremental sales of natural gas energy units measured as Dekatherms (one million BTU). On the engineering side, though, the storage pool cap/del working unit is volume, not energy units. To talk sensibly of both, a conversion is used - volume in thousands of cubic feet of natural gas (Mcf) to BTUs as Dekatherms. The conversion assumes 1,000 BTU of heat energy in each MCF of natural gas. So the conversion is a straightforward one: 1,000 Mcf equals one million BTU equals one Dekatherm. So, one MMcf (one million cubic feet) of natural gas equals one Dekatherm. This convention will be used in this paper.

To present a case for the economy of FOX, a hypothetical baseline case is established. The actual incremental increases in value of the natural gas storage pool commodity, sold as storage service (capacity or deliverability) cannot be known without examining the complete structure of the storage pool's rate design, a study beyond the ambitions of this paper. The baseline case will assume a $1.00 increase in revenue for each Mcf of added (incremental) top-gas capacity. The incremental values in deliverability will proceed then from this $1.00 baseline. So:

Capacity: A one Mcf increase will result in a $1.00 increase in revenue.

Deliverability (First-Day & Last-Day) an incremental increase in deliverability manifests market value in two ways: 1) a larger market (customer-revenue) base can be served with the same capacity and physical plant and 2) a greater deliverability allows the storage pool operator to cycle the storage pool more often (increase cycle frequency) presenting an non-operational increase in capacity. The baseline case will prevail: a $1.00 increase in revenue for each one Mcf incremental increase in first-and-last-day deliverability.

Deliverability: (Peak) a one Mcf increase will net a $2.00-$3.00 increase in revenue.

When the incremental cap/del increases are effected by hydraulic fracturing, there is a cost. The gain-in-revenue realized by the frac-induced increase in cap/del is measured against that cost using rate-of-return analysis. The incremental future revenue stream is discounted to present at some discount rate, and the rate-of-return calculated.

So, cost is a critical issue, and the containment of cost paramount. Cost can be controlled by optimizing the hydraulic fracturing that is done, to wells or groups of wells, by getting maximum increases in cap/del for minimum frac costs. This end is achieved by frac-design optimization, using FOX.

Lost-Opportunity Economics

Figure 3 shows the actual post-frac deliverability, the predictor's module's results and the optimizer's result. The optimizer's result are post-frac deliverabilities that could have been achieved if FOX was used during the design process. The predictor's module results are presented in this figure to deliver the following point. Since both the predictor's results and the optimizer's results are the outcome of the same neural network, it is assumed that optimizer's results are as accurate as those of the predictor's. Data for this figure are presented in Table 1.

For the eight-well universe (the eight wells re-fraced in 1991), Figure 3 shows that the use of FOX could have increased post-frac deliverability another 3,123 Mcf per day over the increase actually realized (Table 1) . While the predicted FOX post-frac volumes are higher, the incremental revenues to-be-generated by the FOX frac, had it been used, become opportunity costs. The incremental revenue that would have been generated had the FOX application been used in frac design is lost. And the lost revenues are quantifiable.

An example: In 1991, eight wells were re-fraced using the conventional, non-FOX, frac designs. The wells showed a total 4,590 Mcf/Day post-frac deliverability against a software-predicted post-frac deliverability of 4,507 Mcf/Day. The software prediction, within 2% of actual, is statistically significant, and is useful in predicting what a FOX-designed re-frac program would have yielded in post-frac deliverability.

The software was used to make a FOX-System post-frac deliverability prediction. The prediction was for a daily post-frac deliverability of 7,714 Mcf, 3,124 Mcf/Day (nearly 70%) over the actual.

That 3,124 Mcf/Day in increased post-frac deliverability was lost when the FOX-designed frac was not used. Assuming the hypothetical baseline model, for first and last day deliverabilities, the lost revenue totals over $3,000 per day for each day. For peak-day deliverabilities, the lost revenue approaches $6,000-$9,000 per day for each day of lost deliverability. The net present value (discounted at 12%) of the lost revenue streams calculates to just over $2 MM for the first and last-day deliverabilities in a 120-150 day storage withdrawal season. For the peak-day lost deliverabilities, the net present value is from $4 MM-$6 MM in lost revenue.

Again, the economics of FOX, and the lost opportunity costs associated with non-FOX frac designs, are real costs. Still, as presented in this paper, the dollars shown are hypothetical. The baseline case for gas storage pool economics in this paper is an assumed $1.00/Mcf in revenue increase for each incremental increase in pool capacity. Any actual economy would have to be computed using the pool's rate structure.

CONCLUSIONS

Fracture Optimization eXpert (FOX) is a new and novel hydraulic fracture design optimization tool that has been developed using neural networks and genetic algorithms. This tool, in its current form has been custom designed for gas storage wells in Clinton Sand in Ohio. FOX's unique concept has been programmed into a modular design. After proper modifications, this concept, and the software, can be applied to not only the storage fields with historical data, but also to production fields and wells with no historical data. It was shown that use of this concept and tool can result in millions of dollars savings and extra revenue.

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Table 1. FOX results for 1991.

Well	Field Results	Predictor Module	Optimizer Module	% Inc.	Diff. Mcf/D
1339	590	533.0	724.6	22.81	134.6
1381	405	449.2	857.9	111.83	452.9
1670	626	677.1	1195.7	91.01	569.7
2212	793	898.7	1260.3	58.93	467.3
2261	512	504.0	877.8	71.37	365.4
2310	523	427.2	823.8	59.24	309.8
2826	401	428.8	902.7	125.11	501.7
3161	740	589.4	1061.6	43.46	321.6
Total	4590	4516.3	7704.4	%68	3123

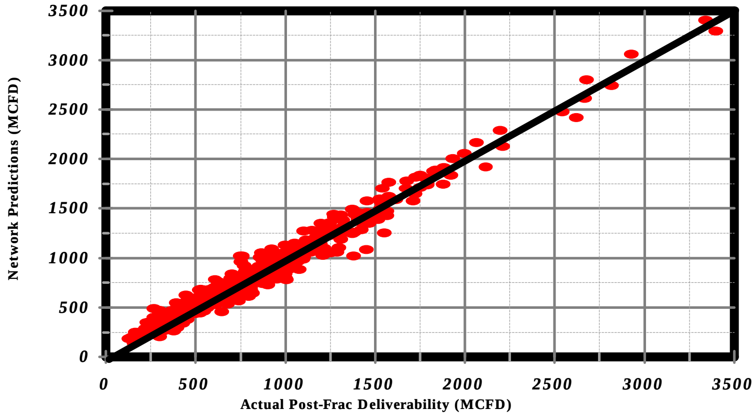

Figure 1. Network performance for data used in training.

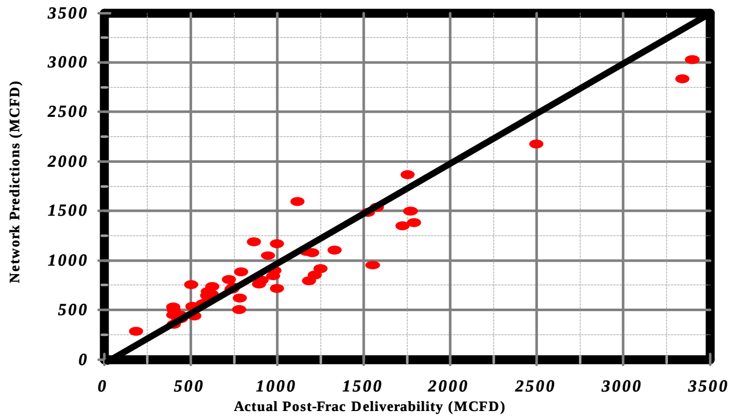

Figure 2. Network performance for verification data.

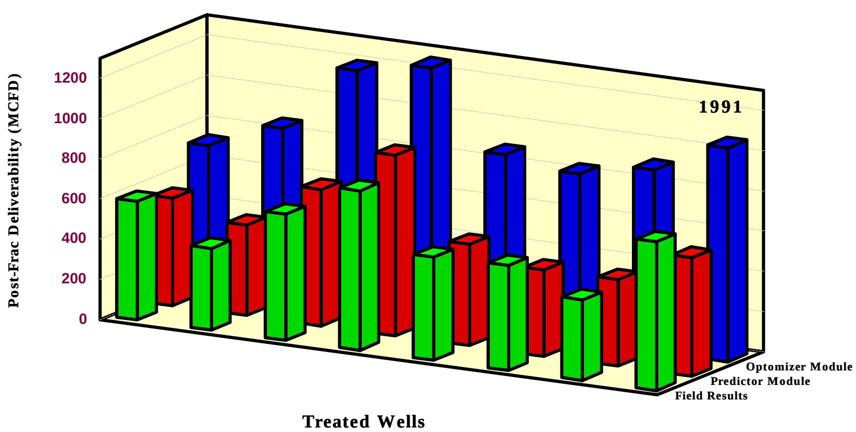

Figure 3. Enhancements that could have been achieved if FOX was used.