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The Fuzzy Expert Exploration Tool for the Delaware Basin: Development, testing and applications

S.M. Schrader [a,*], R.S. Balch [b], T. Ruan [b]

[a] Department of Petroleum Engineering, Montana Tech, Petroleum Building 208, 1300 W. Park Street, Butte, MT 59701, United States
[b] Petroleum Recovery Research Center, New Mexico Tech, United States

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ABSTRACT

The Delaware Fuzzy Expert Exploration Tool (FEE Tool) is an expert system designed to reduce exploration risk for the Lower Brushy Canyon formation of the Delaware Basin. The components of the Delaware FEE Tool include a knowledge base containing sets of rules developed through expert interviews, an answer base of numerical inputs to these rules, an inference engine that uses fuzzy logic to evaluate the rules with answer base or user-provided data, and a user interface where the user can work with input data and interpret the tool's results.

For each of 60,478,40-acre locations in the New Mexico portion of the Delaware Basin, the FEE Tool output includes a scaled quality estimate in the set {0, 1}, with a value of 0.65 or greater, indicating a low risk prospect. In testing, the quality estimates were found to be significantly higher at locations where recent successful wells were located.

The Delaware FEE Tool was also used as a reserve estimation tool by relating the FEE Tool estimate at a known producing well to its total expected production. Then the FEE Tool estimates at undrilled locations were used to calculate a reserve estimate. Using this approach, the probable regional reserves were estimated to fall between 278 and 432 million bbls.

1. Introduction

Soft computing techniques including expert systems, fuzzy logic and neural networks, are powerful tools with many applications in the petroleum engineering field.

An expert, or knowledge-based system, is a computer program that allows the user to apply knowledge collected from experts to solve a problem. An early example of the use of expert systems in petroleum engineering was the MUD system; an expert system developed to help users' select appropriate drilling muds (Kahn & McDermott, 1993). The MUD system stored expert knowledge in a series of rules contained in a knowledge base. A second example of a knowledge-based expert system is the RELPERM software (Ali & Fawcett, 1996). This system contains expert-derived rules that help the user to acquire relative permeability models for use in reservoir simulators while minimizing the need for costly laboratory studies. Another example is the development of an expert system to aid diagnosing formation damage mechanisms and designing stimulation treatments (Xiong, Robinson, & Foh, 2001). In this system the knowledge base was developed through the use of interviews, literature reviews and field examples.

Fuzzy logic is a type of logic in which an element can have partial membership in a set. In classical or predicate logic, an element is either a member or not a member of a set. For instance, it may be reasonable to describe a well as having been either completed or not completed; however it may not be reasonable to describe a formation rock as porous or not porous. In the latter case, linguistic terms such as slightly porous or highly porous might be used to describe the rock. Fuzzy logic provides the mathematical tools to work with these types of descriptions. Many expert systems, such as the formation damage system (Xiong et al., 2001), use fuzzy logic to store and evaluate expert rules. When the inference engine (the process in which the rules are evaluated) is based on fuzzy logic, the system may be termed a fuzzy expert system. The FEE Tool is an example of a fuzzy expert system, as is a program termed MULTSYS (Garrouch, Lababidi, & Ebrahim, 2004), a web-based fuzzy expert system designed to aid in well completion.

Neural networks are a type of soft computing in which, after exposure to data, the machine "learns" to recognize patterns. A neural network consists of a network of artificial neurons designed to mimic the biological neurons in the human brain. In most applications, the neural network is trained by providing it with data sets, including the input data and the desired outputs. The difference between the neural network output and

* Corresponding author. Tel.: +1 432 552 2217.
E-mail address: sschrader@mtech.edu (S.M. Schrader).

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the desired output is used to modify and fine-tune the network. Data are held aside for testing once the network achieves the desired level of performance. Neural networks are often applied in the petroleum industry to deal with large datasets that may not be easily analyzed with conventional methods (Mohaghegh, 2000). One example is the use of a neural network to interpret older well logs (Einstein & Edwards, 1988). In this case the neural network was able to perform comparably with human experts.

In order to take advantage of these techniques, the Delaware Fuzzy Expert Exploration Tool (FEE Tool) has been developed to reduce the risk of developing wells in the Lower Brushy Canyon formation of the Delaware Basin. The FEE Tool shares many of the features of these expert systems; it is centered on a knowledge base containing an extensive collection of if–then rules, it uses fuzzy logic in the inference engine, an input to the FEE Tool was developed using neural networks, and the tool is available online.

The Lower Brushy Canyon formation was selected for this work for a number of reasons, including the amount of available public domain data and number of available experts with a good understanding of the formation. Upon the completion of the Delaware FEE Tool, a similar tool was developed for the Siluro-Devonian Carbonate formation of southeast New Mexico. These tools are currently available for use and techniques developed for the construction of these tools are currently being applied to the development of a customizable expert system. This new system will be able to aid in petroleum exploration for any formation or play of interest.

The FEE Tools provide a numerical output, termed the quality estimate, for each gridpoint or drill site in the region. The quality estimate is a number between 0 and 1, with a value close to one indicating that the system considers the location favorable. Evaluating the quality estimate at locations of producing wells held aside during the development provided one method of testing the tool. In that testing, the FEE Tool was able to recognize good drilling prospects.

As an exploration aid, the FEE Tool has been received with interest by producers and operators in the region. In addition, it has also been applied to the calculation of Lower Brushy Canyon oil reserves.

2. Development of the FEE Tool

The FEE Tool consists of a knowledge base of expert-provided rules, an answer base with the available inputs to the rules, an inference engine that evaluates the rules and provides a quality estimate, and an interactive user interface where the user can view the rules and inputs, modify the inputs, and review the results. Screen shots of the FEE Tool, showing a page where the user reviews the rules and inputs, and a summary page of results, are given in Figs. 1 and 2.

2.1. Knowledge base

The first step in developing an expert system is to collect expert knowledge. For the FEE Tool, interviews were conducted with individuals experienced in Lower Brushy Canyon exploration. Notes from these interviews were used to form a preliminary knowledge base. The rules in the preliminary knowledge base were evaluated, reviewed, and correlated to production. Based on this review, the rules were fine-tuned and organized into the final knowledge base (Schrader, Balch, & Ruan, 2003).

The knowledge base was organized by dividing the rule sets into three branches: a trap branch with rules for evaluating the trap quality, a formation branch that considers the quality of the source rock, and a regional branch evaluating the predicted production data. Each branch begins with a set of rules that determine an initial estimate and the remaining rules in the branch modify the estimate by enhancing or degrading it.

The first part of the trap branch is a set of rules that considers distance to the nearest producing well or oil show; the remainder of the branch includes rules about thickness of the porous sand and existence of an updip sand pinchout. The formation branch begins with a set of rules involving total organic carbon and its remaining rules relate to measures of thermal maturity. The final branch, the regional, begins with a set of rules based on the amount of predicted production at the prospect. The values of predicted production were developed with a neural network using geophysical attributes as input variables (Balch, Hart, Weiss, & Broadhead, 2002). The latter part of the regional branch comprises a set of rules involving the consistency of predicted production in a neigh-

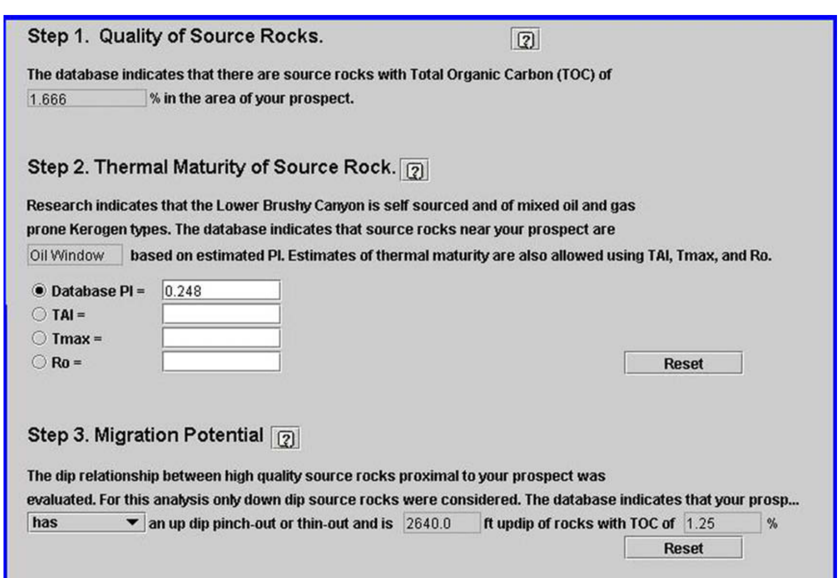

Fig. 1. Screenshot of the Delaware FEE Tool, showing a screen in the Formation section. Users can review the answer base data, and may replace values with their own data on this screen. Similar screens exist for the Trap and Regional sections of the tool.