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A structured approach to the diagnosis of formation damage caused by organic scale deposits and surface active agents, Part I: Development of a Diagnostic Process

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ABSTRACT

A structured approach has been proposed for diagnosing formation damage caused by organic scale deposits and surface active agents. The approach is based on a comprehensive set of heuristic rules governing the formation of emulsions, water blocks, and wettability reversal as well as the deposition of asphaltenes and wax in hydrocarbon reservoirs. The compiled rules, representing experts' knowledge, have been derived from standard industrial practices and integrated with empirical models to ensure a robust view of the diagnosed damage types. The knowledge has been arranged in decision trees that form the core structure of a diagnostic process to identify types of formation damage. The damage diagnostic process is performed by walking through the history of the reservoir from drilling to production, stimulation, EOR processes, and workover jobs. The complete history of the well is carefully scrutinized for evidence of any field practices that might cause formation damage. The developed approach and knowledge has been tested with 3 comprehensive hypothetical cases that simulate a wide range of damage problems. This approach has also been validated with two documented field cases that involve producing wells in the West Coalinga field in California and in the Ghawar field in Saudi Arabia. Both cases resulted in thorough diagnoses of damage types in agreement with field observations.

This paper forms the first leg of a two-part series: (I) Development of a Diagnostic Process, and (II) Expert System Development. Part I proposes a structured approach for diagnosing formation damage. Part II automates the diagnosis process developed in Part I.

1. Introduction

Organic-related damage has been shown to be the cause of the significant decline in oil production for many producing wells around the world (Newberry and Barker, 2000; Kokal et al., 2003). Many of these wells completely ceased production while others became intermittent producers, thus presenting real challenges for restoring production. Bennion et al. (1995) and Economides and Nolte (2000) presented a comprehensive list of the formation damage types that may affect a hydrocarbon reservoir. Organic scale-related damage may be caused, for instance, by asphaltenes or wax deposition or asphaltene sludge. Hydrocarbon rock contact with surface active agents may cause emulsions, water blocks, and wettability reversal. Almost every stage in the reservoir life, from drilling, production and stimulation to enhanced oil recovery processes, may cause reservoir damage. Even acidizing operations may be the source of formation damage in sandstone reservoirs if the compatibility between the injected acid, the rock mineralogy and the crude type are not carefully accounted for (Ebrahim et al., 2014). This significant loss in production incurs major revenue losses, estimated in the billions of dollars each year (Ding and Renard, 2005).

The process of damage diagnosis is a lengthy and complex endeavor that is better managed when structured. The objective of this study is to develop a structured approach to the diagnosis of formation damage types related to organic scale deposits and surface active agents. This approach is based on a comprehensive set of heuristic rules governing the formation of emulsions, water blocks, and wettability reversal as well as the deposition of asphaltenes and wax in hydrocarbon reservoirs. In Part II of this work, the proposed approach will be automated by developing an expert system.

1.1. Diagnostic process structure

The methodology used in this study consists of two consecutive steps. The first step identifies all potential external sources of damage by soliciting perforation skin, partial penetration skin, gravel pack skin, skin associated with high flow rate of fluids, and

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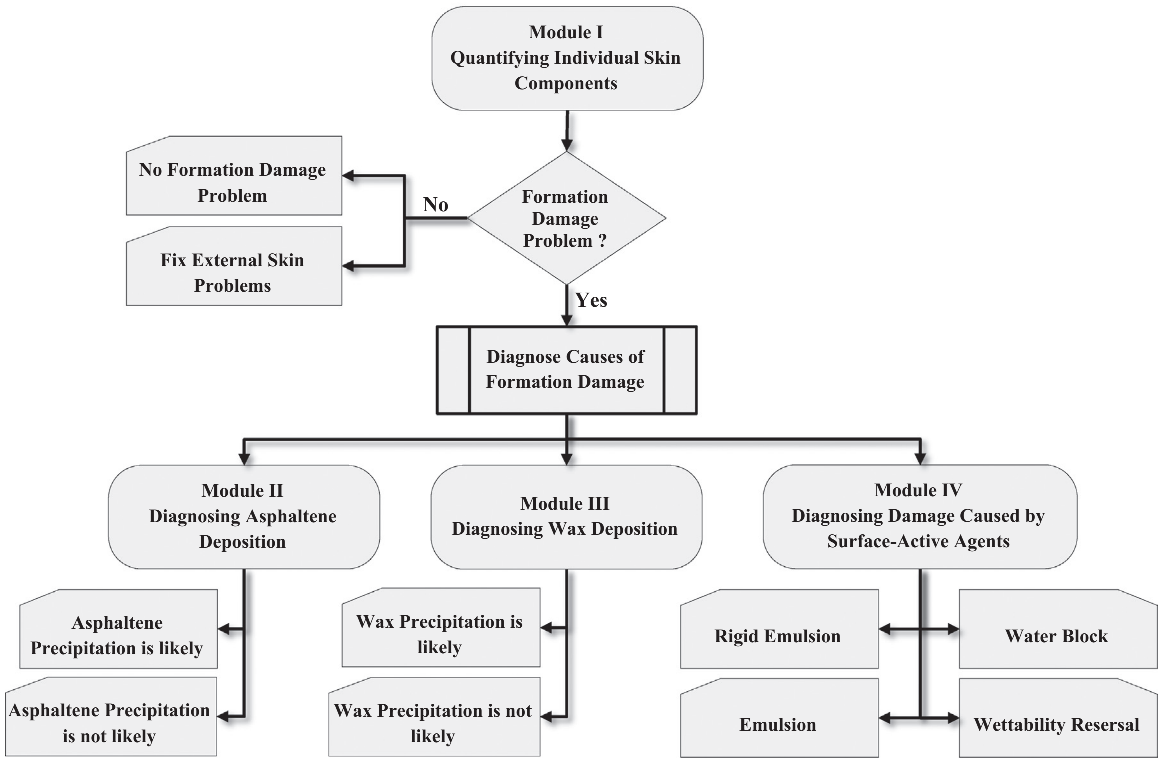

Fig. 1. Structure of the formation damage diagnostic expert system.

slant skin. An accurate estimate of these external damages allows for the determination of formation damage. Once formation damage skin is evaluated, the second step attempts to diagnose the types of damage mechanisms inflicting a given layer using a "life-cycle" approach, by walking through the life of the formation. The life-cycle approach scrutinizes the drilling operation, well completion, production operations, or any acidizing jobs that have been performed on a given reservoir unit. With this comprehensive approach, it becomes difficult to miss the diagnosis of any type of formation damage that is causing a decrease in production.

The structure of the systematic process for formation damage diagnosis is shown in Fig. 1. It consists of four modules, which are discussed further in the following sections:

Module I. This module evaluates formation damage skin.
A diagnostic session starts by activating this module. Inputs of the individual damage components are used to discern external damage from actual formation damage. If formation damage exists, the remaining three modules (II, III and IV) are activated in sequence to diagnose the type of formation damage (Fig. 1).
Module II. This module diagnoses potential asphaltene deposition.
Module III. This module diagnoses potential wax deposition.
Module IV. This module diagnoses potential damage caused by emulsions, water blocks, and wettability reversal.

2. Decision trees

Knowledge elicitation (or acquisition) is the first step in developing a knowledge-based system. It is performed through direct interaction between the domain expert and the knowledge engineer or the developer of the system. During knowledge acquisition sessions, knowledge is acquired in the form of rules, procedures and conditions. Following each session, knowledge is then refined and represented in a format that can be interpreted by both parties.

Decision trees are used in the current work to represent acquired knowledge and reasoning logic. A *decision tree* is a tree-like decision support tool that uses a graph to convey decisions and their possible consequences (Adamo, 1980; Yuan and Shaw, 1995). It primarily contains three types of nodes: *decision nodes* associated with conditions and statements to support decision making, *chance nodes* to represent derived decisions and events that are likely to occur, and *end nodes* corresponding to situations and end goals to be obtained. The decision trees that were developed for the four modules are described in the following sections.

2.1. Module I. Evaluating formation damage skin

The decision tree for Module I is presented in Fig. 2. The three main tasks performed at this stage are as follows:

a) Estimate the skin caused by damage inside the reservoir.
b) Indicate whether mechanical problems exist in the well.
c) Make a decision whether to proceed with the formation damage diagnostic process or to terminate the diagnostic session.

Based on the value of total skin from well testing (S_t), reasoning in Module I is initiated to appraise the existence of a formation damage problem and decide whether further investigation should continue or terminate at one of the end nodes. Formation damage diagnosis is executed by processing Modules II, III and IV if neither mechanical problems are anticipated nor production problems are encountered, or if the value of formation damage skin (S_d) is positive. Production problems may exist if a sudden decrease in production is observed, the well does not flow, or if the well is produced at high drawdown.

Module I requires the input of individual external skin components to estimate the skin inside the formation. Using the Samaniego-Cinco Ley Model (Golan and Whitson, 1991), the total