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Review article

A holistic review of geosystem damage during unconventional oil, gas and geothermal energy recovery

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ABSTRACT

Formation damage issues typically arise at different recovery stages of unconventional oil/gas and geothermal energy in various petroleum and hydrological geosystems. A lack of understanding of the potentially induced damage in those geosystems is associated with downside risks and negative economic consequences. As a comprehensive review and analysis building upon our previous work (Yuan and Wood, 2018), this paper aims to raise more awareness of the mechanically, chemically, biologically and thermally induced damage issues associated with oil/gas and geothermal energy recovery in unconventional shale, coal-bed methane, geothermal reservoirs, and deepwater oilfields. It does so by integrating state-of-the-art modelling, laboratory experiments and field examples. Potential formation damage issues are discussed in the context of each specific geosystems to answer why, where and when damage occurs, its extent and impacts, and how to control, prevent and take advantages of such issues. Moreover, an integrated risk and opportunity assessment and management framework is presented with the objective of improving the outcomes of energy extraction projects in practice.

1. Introduction

The consumption of crude oil is expected to contribute some 26% of the world's energy until 2040 [2]. To meet the growing demands and constraints on energy resources, oil operators have to exploit more complex reservoirs (unconventional shale, coal-bed methane, and green geothermal energy etc., as shown in Fig. 1 [3]), but to do so requires more advanced technologies. In lower-oil-price markets and profit-competitive environments, it is of particular interest to improve the efficiency of oil and gas recovery techniques from various reservoir systems by minimizing potential risks and costs.

Traditionally, the oil and gas industry has not primary focused on formation damage in high-oil-price environments, although formation damage is frequently a consequence of the implementation of oil and gas production techniques. Civan summarized the relevant causes of formation damage and its consequences, and various approaches and techniques for formation assessment, control and remediation [4]. Generally, formation damage refers to the impairment of physical, chemical or mechanical properties of petroleum-bearing formation, which primarily involves permeability damage during various processes of oil and gas recovery. The changes of chemical-physical-thermo-dynamic conditions associated with various injection or production techniques can result in various types of formation damage, such as, water/oil droplets and gas bubble blockage, fines/sands migration, in-situ fluids-rock incompatibilities, organic and inorganic scaling precipitation and deposition, chemical-physical damage of pore surface properties, alternation of pore structures and mechanic characteristics, etc. Formation damage can be described as the reduction of the fluid deliverability owing to various processes, especially in the near-well regions, and can be also expressed as the hindrance of the fluid mobility toward the wellbore owing to the alteration of flow parameters and interactions of different fluid phases with each other, as well as with the boundaries of the flow paths. In some cases, formation damage may itself lead to some benefits to enhance oil recovery, for instance, improving sweep efficiency thorough selected blockage of high-permeability regions caused by fines migration [5,6]; however, more usually, it reduces the efficiency of oil, gas and geothermal recovery from the reservoir and impairs well injectivity and/or productivity dramatically [7]. Hence, in this work, formation damage will not be simply be addressed as "problem", but rather as "issue", reflecting its potentially positive and negative effects on well productivity and economic performance.

By the nature of reliability, sustainability, abundant resource and minor impacts on environment, geothermal energy is considered as one of the future resources to meet the worldwide growing energy demand. However, during the injection/production of water through geothermal

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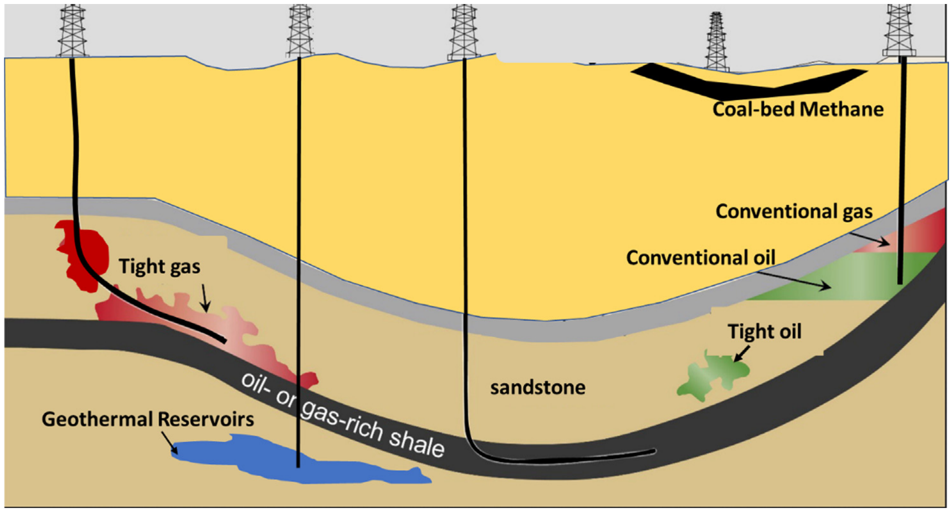

Fig. 1. The schematic presentation of various geosystems contained oil, gas and thermal energy: revised after US Energy Information Administration (EIA) [3].

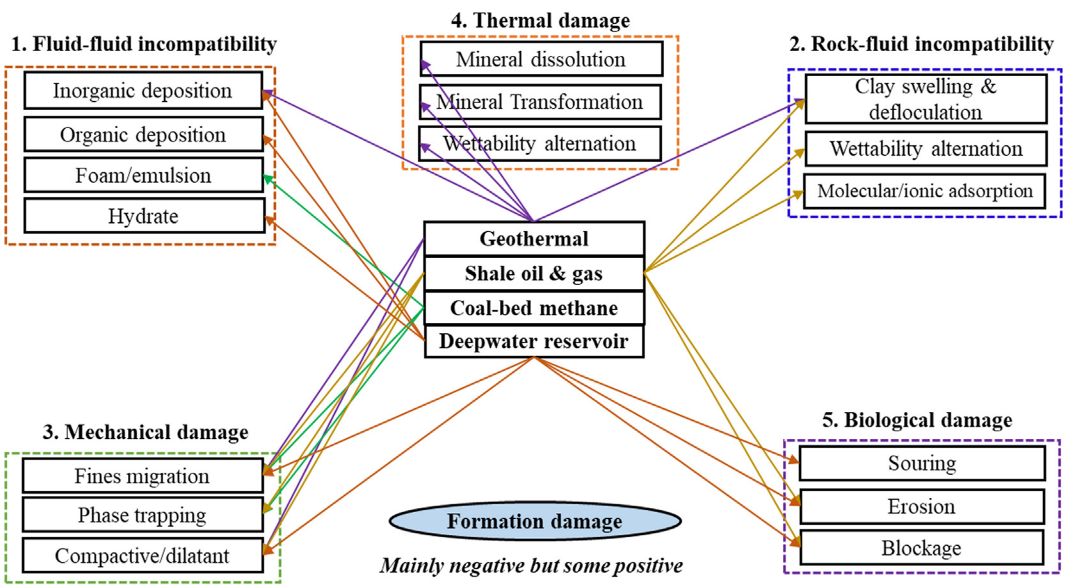

Fig. 2. The potential formation damage mechanisms linked with oil, gas and thermal recovery in types of reservoirs.

reservoirs, the decrease of temperature in geothermal reservoirs not only interrupts the in-situ thermal-chemical equilibrium, but also introduces or amplifies mechanical formation damage processes in the subsurface. In geothermal reservoirs, maintaining high rates of fluid circulation is essential to guarantee the economically-viable exploitation of geothermal systems. However, the conditions of high flow rates and variable temperature distributions can trigger the significant decline of well injectivity and productivity by exaggerating the transport and plugging of clay particles and permeability impairment [8]. Therefore, the assessment and quantification of induced formation damage is also a vital part of the feasibility study of geothermal energy projects.

Porter stated that it is better to avoid formation damage in advance than to make tremendous efforts to remediate it after it has occurred [9]. Formation damage could be potentially realized during drilling, completion, workover, stimulation, fluids injection and production, and improved or enhanced recovery operations. The studies of formation susceptibility to damage have limited practical values if conducted without linking them to the associated engineering activities, which may or may not lead to more severe potential damage. Hence, it is essential for production operators to understand formation damage specific to various geo-energy systems, because it enables them to strive towards maximizing the profits from oil, gas and geothermal production by reducing the impacts and remediation costs associated with formation damage. A dual technical and economical focus as part of a co-optimization strategy can help to optimize geo-energy recovery and operation profits, while recognizing that a fine balance needs to be achieved between these factors. To do that, a comprehensive integration and analysis of modelling, simulation, laboratory experiments and field testing are required to predict, characterize and control any risks of formation damage. Such approach also aids the development of new advanced technologies and methodologies capable of addressing formation damage in both conventional and unconventional reservoirs. As an extension of our previous work [1], the intention of this review is to provide a better understanding of potential formation damage issues in specific unconventional geosystems; for example, shale oil and gas, coal-bed methane, deepwater oilfield, and geothermal reservoirs. We also provide guidelines on how to best control or take advantages of formation damage by optimizing the design of petroleum and energy extraction projects.

In this work, rather than concentrating on the fundamental theories related to individual recovery mechanisms and formation damage