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Geophysical monitoring of a hydrocarbon reservoir

Enrico Caffagni[a,*], Götz Bokelmann[a]

[a]Department of Meteorology and Geophysics, Althanstrasse, 14 (UZA II), Vienna 1090, Austria

Abstract

Hydrocarbon extraction from unconventional reservoirs demands ever-increasing technological effort, for better understanding phenomena occurring within the reservoir.
We review currently available geophysical techniques for reservoir monitoring. First, we describe basic characteristics of geophysical monitoring, identifying properties and their associated monitored quantities, according to the different fields of analysis in reservoir. Second, we present an overview of current monitoring techniques associating them to monitored quantities.
Monitoring is extremely important in understanding how the reservoir reacts to external or internal perturbation of its state; secondly, monitoring is one of the first steps in preventing and addressing key environmental issues.

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1. Introduction

Hydrocarbon reservoirs are composed of rocks containing different minerals, fluids (water) and hydrocarbons (oil or natural gas). Natural reserves can be trapped in geological formations at variable depth depending on the geological conditions in the reservoir. Each reservoir is characterized by its natural conditions, such as faulting and folding that contributed to the formation of an existing network of natural fractures.

In unconventional reservoirs, hydrocarbons might be distributed throughout the reservoir at the basin scale, trapped in low permeability formations such as, 'pinchouts', where buoyant forces are not significant. Therefore rock-breaking techniques such as hydraulic stimulation (Hydraulic Fracturing) are needed to optimize the flow recovery. Typical unconventional reservoirs are: tight-sand, shale, sandstone.

Hydraulic-Fracturing (HF) is a sophisticated technique which is widely applied in low-permeability geological formations to enhance the production of natural hydrocarbons. It consists basically of breaking the rock by high-pressure fluid injection, creating an extensive network of fractures, that hydrocarbons can easily flow through. HF is a component of the whole cycle of hydrocarbon production, along with the usual practice in oil-gas industry of injection of

* Corresponding author: Tel: +43-1-4277-537 73
E-mail address: E-mail address: enrico.caffagni@univie.ac.at (Enrico Caffagni).

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co-produced water ('wastewater disposal'), that can be re-used, for instance, in reservoir depletion [6].

Hydrocarbon extraction in massive usage represents the most economically efficient way of energy production. However, despite the undeniable economical benefit, a plausible, yet concerning, relationship between oil-gas industrial activity and serious geohazards, has been recognized, such as an increase in seismicity (e.g., [2]). In addition, episodes of fresh water contamination due to gas stray migration propagating in abandoned or improperly-cased wells have been reported in the literature (see [3]).

In principle, similar HF techniques have been applied also in Europe for a long time, yet in conventional reservoirs, and are likely to be intensified in the near future. When HF is used, especially in the form of the much-discussed "fracking", knowledge of the state of the reservoir becomes important, both for optimizing operations, and also to safeguard against potential environmental hazards. This suggests an increasing demand in technological development, including updating and adapting existing techniques in applied geophysics.

The first attempts of tracking temporal changes (monitoring) in hydrocarbon reservoirs are dated 40-50 years ago. These surveys were mainly focused on characterizing the subsurface using probes, such as seismic and electric, deployed in boreholes or at the surface. Reservoirs are nowadays monitored during exploration and exploitation of the hydrocarbons by using different monitoring techniques, according to the geological conditions. Techniques have been developed and are still in usage in off-shore plays, such as, seismic Permanent Reservoir Monitoring (PRM), with different design from the on-shore case. Some of these techniques aim at constructing images of the reservoir compartments; others can estimate important parameters directly in-situ.

In this work we review currently available geophysical techniques for reservoir monitoring. First, we describe basic characteristics of geophysical monitoring, and we identify properties and the associated monitored quantities in a hydrocarbon reservoir, according to the different fields of analysis in reservoir. Second, we present an overview of current monitoring techniques associating them to monitored quantities.

2. What is Geophysical Monitoring?

Hydrocarbons are extracted from unconventional reservoirs by artificial stimulation, such as HF, which can dramatically affect the geo-mechanical response of the reservoir. Stress alteration and sudden increase in pressure can generate significant changes of the reservoir characteristics.

Geophysical monitoring implies keeping track of temporal changes of characteristics (later called "properties") of a reservoir that are imposed by external or internal perturbation of the reservoir state; such changes may not only allow inferences to be made on the reaction of the reservoir to the perturbation (e.g., in terms of deformation, fluid flow or temperature changes), but also give information on reservoir properties that were previously hidden (e.g., [7]). Monitoring can be achieved by implementing probes in-situ (directly into the reservoir), or outside of the reservoir, where the non-invasive nature of the method prevents any further perturbation of the reservoir

Let us assume that a hydrocarbon reservoir is analyzed in-situ at time t_0. If no external stimulation is applied, the reservoir is unaltered, and remains in its *initial state*. Natural variations can be due to the background stress in the underground rocks, forces of tectonic, volcanic, or tidal origin, presence of faulting/folding, fracturing, or presence of fluids, such as water and hydrocarbons. At time t_1 an artificial stimulation starts to be applied and it is terminated at time t_2. The time interval between t_1 and t_2 refers to the stimulation; much of its effects should occur within this time interval, on top of any occurring natural variations. After t_2, the stimulation is stopped, however significant effects may still occur, and the reservoir will unlikely return to its exact initial condition at t_0. After a certain time, changes may not be detected anymore; however the reservoir characteristics will usually differ from those at t_1.

Monitoring refers to tracking the temporal changes of the reservoir, starting from its initial state at time t_0, to a possibly long time after t_2. A baseline study of the hydrocarbon reservoir should be conducted before the stimulation (e.g., fracking) to obtain the background state, which provides an objective point of comparison for the reservoir state as measured during and after the stimulation. In this way, both the natural and artificial components of the deformation processes can be tracked; where possible, these two contributions should be distinguished, even though nature and anthropical effects can be tightly bound.