SPE 115715

Correlation Between Microseismicity and Reservoir Dynamics in a Tectonically Active Area of Colombia

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This paper was prepared for presentation at the 2008 SPE Annual Technical Conference and Exhibition held in Denver, Colorado, USA, 21–24 September 2008.

Abstract

BP operates the Cusiana volatile oil field and the Cupiagua gas condensate field in the Andean Mountains foothills province of Colombia **(Fig. 1.)**. In 1992, a permanent seismic network of ten surface stations was installed in Cusiana and Cupiagua to obtain data for seismic hazard models necessary for the design of field infrastructure. The network is now in its sixteenth year of continuous operation. Currently, an average of 1000 microseismic events per month is recorded. The resulting seismological dataset is of high quality covering a range of seismic magnitudes down to about 1.0 on the Ritcher scale.

Over time, the Cusiana-Cupiagua Seismic Network (CCSN) has been used for different purposes. During the past few years, it has become increasingly evident that the network and its data is an invaluable asset for evaluation of conditions relevant to production/injection operations within the reservoirs and adjacent areas.

From the reservoir characterization and production operation standpoints, microseismic monitoring (also known as passive seismic) has had two main applications in Cusiana and Cupiagua: (i) to identify production/injection induced high transmissibility pathways and their temporal variations, and (ii) to image the orientation, extension, complexity, and temporal growth of hydraulic fractures.

This paper is focused on the first of these applications: how microseismicity has been used as a surveillance tool to track movement of reservoir fluids away from the wellbore. A short description of the seismic network is provided. Then, the methodology for data interpretation is discussed. Finally, partial results are presented showing how microseismicity monitoring is being applied to: (i) assess transmissibility changes due to stress and pore pressure changes through time, (ii) identify potential reactivation of pre-existing weak planes, and (iii) calibrate numerical models to improve history matches.

Analysis of the data shows a strong correlation between reservoir dynamics and production induced microseismicity in Cusiana and Cupiagua Fields with great potential as a surveillance tool for improved reservoir characterization and management.

Introduction

Oil and gas production and injection change the pore pressure and the stress state in the reservoir. These changes give rise to a change in volume of both reservoir fluids and reservoir rock. The volumetric behavior of the reservoir fluid is controlled by the fluid composition and the change in the pore pressure and is not the subject of this paper. The volumetric response of the reservoir rock depends on the mechanical properties of the rock material (matrix and pre-existing fractures) and the combined effect of changes in pore pressure and stress state.

Conventional reservoir engineering incorporates the implicit assumption that the local stress state within the reservoir remains constant with time. Thus, no deformation of matrix and natural fractures, caused by stress changes, take place during the reservoir producing life. In this case, reservoir dynamics are governed only by changes in pore pressure. However, field observations show that the magnitude and direction of production/injection induced stresses may change throughout the reservoir with time (Saltz 1977; Avashthi et al. 1991; Teufel and Ferrel 1990 and 1992; Cornet and Jones 1994; Wright et al. 1995; Wright and Conant 1995).

These changes in the stress state, combined with changes in pore pressure, may have significant effects on dynamic reservoir behavior. In particular, natural fracture deformation associated with production/injection induced stresses may affect transmissibility and, therefore, productivity. From the geomechanics standpoint, fracture deformation is equivalent to the reactivation of pre-existing discontinuous planes, which manifests itself as microseismic activity. Most of these microseismic events have much less energy than the smallest earthquake that can be felt by a human at the earth's surface.