Integrated 4D Microgravity to Monitoring a Steamflooding in a Heavy Oil Field

Yousaf Y. Al Sulaimi[1], Mahra Hadhrami[1], Ahmed al Raqmi[1], Ali Al Ismaili[1], James Shorter[1], Jan Stammeijer[2], Sultan Al Bulushi[1]

[1]PDO
[2]Shell Global

Abstract

Microgravity is a cost-effective geophysical method that provides a good precision tool for reservoir monitoring in a time-laps mode. The fluid density changes at reservoir that can be derived from the microgravity anomaly can indicate a decrease or increase on the masses due to steam injection and or oil production activities. The study field is in the northern of Sultanate of Oman. It is characterized by highly faulted/fractured carbonates and a dome-like structure trending NE-SW, has heavy oil with a high viscosity of 16°API. The field underwent its first steam injection as part of a Thermally Assisted - Gas Oil Gravity Drainage project to enhance oil recovery.

The aim of utilizing a 4D microgravity is to monitor and help build a better understanding and optimizing of steam heave movement spatially and temporally and monitor the desaturation of the heavy oil within the reservoir. A total of 714 stations were acquired using three CG-6 gsravity instruments. An orthogonal survey method was tested, involving gravity measurements along multiple, non-parallel lines to create a grid or matrix of measurement stations.

Various corrections were applied to the data, including sensor temperature, tilt, air pressure, and local height corrections. Local instrument height corrections, exhibiting standard deviations near 3 mm, along with drift and scale factor adjustments. Integration of InSAR data, which showed surface height changes up to 70 mm for uplift and 182 mm for subsidence, bouguer anomaly was applied to facilitate accurate gravity corrections and subsurface analysis. Overall, the survey achieved measurement repeatability of 1.5 μGal and estimated average station errors with a standard deviation of 1.0 μGal, illustrating the effectiveness of the applied corrections and adjustments in enhancing data reliability and accuracy.

Relative microgravity data was inverted to assess reservoir mass changes. A Shell-developed least-square inversion method was utilized to deduce the 4D density changes between the base and repeat surveys, assuming a single layer model. The mean station uncertainties have significantly improved, decreasing from 8 μGal to approximately 1 μGal for the 2023 acquisition. The average data misfit was minimized, resulting in an MRS of 7 μGal, and the absolute average fit after multiple iterations reached 2 μGal.

Inverted time-lapse microgravity data from the last decade, when integrated with dynamic reservoir data, has provided valuable insights into steam distribution and oil desaturation within the reservoir. The surveys conducted from 2015 to February 2023 indicate a total reservoir mass reduction of 4.2 million tons. The inverted density mass change maps suggest a gravity decrease over the main area of steam injection and oil extraction, which is also the region of heightened microseismic activity recorded during the same timeframe. Conversely, an increase in gravity was observed north of the reservoir. For the 2023 repeat survey, the estimated density changes ranged from 356 kg/m^3 to -3362 kg/m^3, highlighting the largest area of observed gravity anomaly coinciding with the steam injection and oil production zones.