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Reservoir characterization using a hybrid of particle swarm optimization: A case study from the Blackfoot field, Canada

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ABSTRACT

The development, management, and optimization of a reservoir depend on precise reservoir characterization. There are several methods for doing this, however in the current work, seismic inversion based on the hybrid particle swarm optimization (HPSO) methodology is used. In this method, a local optimization method called quasi-newton method (QNM), combined with a global optimization method called PSO to maximize their benefits and minimize their downsides are used. The global optimization method takes a lot of time to converge whereas, Quasi-Newton method is rapid, but heavily dependent on the initial model. The present study takes these two limitations into account. To characterize the reservoir, the hybrid PSO uses post-stack seismic data to predict acoustic impedance and porosity in the inter-well zone. The effectiveness of this newly devised method is first evaluated using synthetic data, and then it is applied to the real data from the Blackfoot area in Canada. The findings show that for both the synthetic and real data, the inverted outcomes closely match the observed data. The analysis anticipated that the inter-well acoustic impedance and porosity volume would vary from 6000 to 12000 m/s*g/cc and 5-22%, respectively. These volumes display extremely detailed subsurface data. The analysis of inverted findings reveals an abnormal zone inside the two-way transit time frame of 1045 to 1065 ms, ranging from low-impedance 6500-9000m/s*g/cc, and high porosity >15%. This unconventional area is classified as a reservoir. The method is particularly useful in nearby regions where detailed subsurface information needs to be estimated, even with limited prior data.

Keywords: Seismic inversion, Hybrid optimization, Particle swarm optimization, Quasi-newton method, Reservoir characterization, Blackfoot field (Canada)

INTRODUCTION

Reservoir characterization is a multidisciplinary process in the field of geosciences encompassing geology, geophysics and petroleum engineering. It involves the detailed analysis and description of subsurface reservoirs to understand their properties and behaviour. The primary goal of reservoir characterization is to obtain a comprehensive understanding of the reservoir's geological, petrophysical, and fluid properties (Maurya et al., 2020; Kumar et., 2024; Singh et al., 2024). This information is crucial for optimizing oil and gas recovery strategies and making informed decisions throughout the life cycle of a reservoir. Reservoir characterization based on seismic inversion is a crucial process, a technique used to extract detailed information about the subsurface properties of a reservoir by analyzing seismic data that includes properties such as rock and fluid types, porosity, permeability and acoustic impedance. Several techniques are available, but seismic inversion is used here to characterize the reservoir. This method has become quite popular and requires less prior information for implementation (Maurya and Singh, 2018; Kant et al., 2024a).

Various techniques for seismic inversion are continually evolving (Russell et al., 2003; Kant et al., 2024b), which are broadly classified into two categories: direct inversion and indirect inversion. In direct inversion methods, the acquired data is directly used to derive subsurface information. Conversely, indirect inversion methods involve creating a subsurface model and generating synthetic data, adjusting the model to minimize the difference between synthetic and recorded data. This indirect approach is advantageous as it is less affected by inaccuracies or noise in the data, leading to more robust results (Maurya and Sarkar, 2016; Hema et al., 2024). To adjust the subsurface model in seismic inversion, various optimization methods are typically employed. Optimization seeks to determine input values for an objective function that maximize or minimize its output, essentially minimizing the discrepancy between the model and the real Earth data. These techniques are categorized into local and global optimization methods. In local optimization, algorithms follow the downward slope of the cost function's topology, using gradient information to adjust the model and converge to the nearest minimum, based on the starting model's position. However, local methods may get trapped in a local minimum unless the initial guess is close to the global minimum, especially when dealing with multimodal cost functions. On the other hand, global optimization algorithms aim to converge to the global minimum, even in the presence of complex, multimodal cost functions. Examples of global optimization methods include the Monte Carlo method, genetic algorithms, particle swarm optimization (PSO), simulated annealing, while local optimization methods include, steepest descent, conjugate-gradient, Newton's method and Quasi-Newton methods.

The primary objective of any optimization technique is to determine the optimal solution to a problem, which often