نشریه ژئومکانیک و ژئوانرژی (ژئومکانیک نفت)
GEOMECHANICS and GEOENERGY JOURNAL (GGJ)

Extended Abstract

Evaluation of the Effect of Hydraulic Fracturing on Sand Production Potential in an Oil Wellbore Using the Discrete Element Method

Mohammad Fatehi Marji[1*], Manouchehr Sanei[1], Masoud Yazdani[1], Mehdi Najafi[1]

1- Department of Mining and Metallurgical Engineering, Yazd University, Yazd, Iran

Received: 2025/08/04; Accepted: 2025/12/21

DOI: 10.22107/ggj.2026.584860.1265

Keywords

Sand Production,
Hydraulic Fracturing,
Oil Wellbore,
Discrete Element Method,
PFC2D Software

Abstract

Sand production from unconsolidated sandstone reservoirs is one of the fundamental challenges in the oil industry, leading to equipment erosion, reduced productivity, and increased operational costs. Hydraulic fracturing, although primarily performed to enhance permeability and stimulate the reservoir, can affect wellbore stability and the phenomenon of sand production. However, a quantitative understanding of how the geometric characteristics of hydraulic fractures (such as density and length of cracks) influence sand production rates, especially in moderately cemented reservoirs, remains limited. In this study, a two-dimensional model based on the Discrete Element Method (DEM) has been developed in the PFC2D software to integrally simulate the hydraulic fracture propagation process and the subsequent sand production in three different sections of a real well in the Azadegan oil field. The model was calibrated using triaxial laboratory data, and the relative error in predicting the uniaxial compressive strength was about 10.5%. After applying realistic boundary conditions including in-situ stresses, reservoir pressure, and production pressure, the model was run for three sections with different fracturing histories. Quantitative results showed that in Section 1, which had the highest fracture density and length, the cumulative sand production after two days was significantly lower than in Section 3, which had the least fracturing. The key finding indicates that, under the studied geomechanical conditions, the presence of extensive and dense hydraulic fracturing is associated with reduced sand production. This phenomenon can be attributed to the formation of stable stress arches behind the fractured zones, which counteract the fluid drag force and prevent particle detachment. This integrated simulation approach provides a powerful tool for petroleum engineers to simultaneously optimize hydraulic fracturing design and manage sand production.

1. Introduction

Sand production is one of the most costly and technically challenging geomechanical problems in the oil and gas industry, particularly in sandstone reservoirs [1, 2]. It occurs when the fluid drag force exceeds the cohesive and frictional forces between grains, leading to particle detachment and entrainment into the produced fluid [3, 4]. The consequences include erosion of downhole equipment, blockage of production lines, reduced well performance, and, in severe cases, complete well loss [5]. Worldwide, about 70% of hydrocarbon reserves are in formations susceptible to sand production [6], making its accurate prediction and control a critical technical and economic necessity.

Hydraulic fracturing, on the other hand, is a widely used stimulation technique to enhance productivity by creating a network of fractures around the wellbore [7, 8]. While extensive research has been devoted separately to modelling sand production and hydraulic fracturing using various numerical methods—such as finite element, extended finite element (XFEM), and

* **Corresponding Author:** mfatehi@yazd.ac.ir

discrete element method (DEM) [9–12]—there is a notable gap in understanding the coupled interaction between these two phenomena. In particular, the question of whether hydraulic fracturing exacerbates or mitigates sand production in moderately cemented formations has not been adequately addressed. Previous studies have suggested that, under specific geomechanical conditions, hydraulic fractures may promote the formation of stable stress arches that reduce sand production [13]. However, most of these investigations have been limited to simplified geometries and have not been validated with field data from actual wells. In this study, we aim to fill this gap by developing a calibrated DEM model that sequentially simulates hydraulic fracturing and subsequent sand production in three different sections of a real well in the Azadegan field. The novelty of our work lies in: (1) using an integrated and calibrated model with full operational data; (2) quantitatively comparing three sections with different fracture intensities; and (3) validating the simulation results with available field reports (mud loss and solids production). This paper is organised as follows: after this introduction, Section 2 presents the geomechanical characteristics of the studied formation, Section 3 describes the numerical methodology and calibration, Section 4 presents the results and discussion, and Section 5 gives the conclusions and recommendations.

2. Methodology

2.1. Discrete Element Method and Parallel Bond Model

The numerical simulations were performed using the distinct element method (DEM) as implemented in the PFC2D code [14]. In this approach, the rock is discretised as an assembly of circular particles (disks) connected by elastic-brittle bonds at their contacts. The parallel bond model [15] was employed to simulate the cemented nature of the sandstone. The bonds can transmit both forces and moments; they break when the maximum tensile or shear stress exceeds the corresponding bond strength, thus allowing the initiation and propagation of fractures.

The equations of motion for each particle are solved explicitly using a time-stepping scheme. The critical time step was set to 0.1 times the stability limit to ensure numerical stability. Fluid flow was modelled by assigning a pore pressure gradient and applying a drag force on the particles. The calibration of the micro-mechanical parameters (Table 1) was performed by matching the macro-mechanical behaviour (uniaxial compressive strength, Young's modulus, and Poisson's ratio) obtained from the numerical model with laboratory test data from the reference sandstone [16]. The calibrated model gave a uniaxial compressive strength of 48.8 MPa, a Young's modulus of 14.3 GPa, and a Poisson's ratio of 0.36, which agree well with the experimental values (49 MPa, 14 GPa, and 0.36, respectively), with a relative error of about 10.5% for the compressive strength.

2.2. Model Setup and Boundary Conditions

Three sections (Section 1, Section 2, and Section 3) of a production well in the Azadegan field were selected, corresponding to different hydraulic fracturing histories (highest, medium, and lowest fracture intensity, respectively). For each section, a two-dimensional numerical model with a radius of 3 m was constructed, comprising approximately 150,000 disks with a non-uniform size distribution (maximum-to-minimum radius ratio of 1.66). The in-situ stresses and reservoir properties were taken from field data. Boundary conditions were applied as follows: reservoir pressure and far-field stresses at the outer boundary, and completion pressure and production pressure at the wellbore wall. The hydraulic fracturing process was first simulated by injecting fluid at a prescribed pressure until fracture propagation ceased, and then the sand production test was performed on the fractured model for a duration of two days.

3. Results and Conclusions

The numerical simulations revealed a clear relationship between the extent of hydraulic fracturing and the amount of sand produced. Section 1, which had the highest fracture density and total fracture length, produced the least cumulative sand after two days. In contrast, Section 3, with the fewest fractures, exhibited the highest sand production. Section 2 showed an intermediate behaviour. This trend was consistent across all three sections and was confirmed by the observed reduction in sand production rate after the initial period, indicating that the system approached a steady state.

The mechanism behind this counter-intuitive result is the formation of stable stress arches behind the fractured zones. As the hydraulic fractures propagate, they redistribute the local stresses and create a network of inter-particle contacts that effectively transfer the fluid drag force to the surrounding rock matrix, thereby preventing particle detachment. This arching effect is more pronounced when the fracture network is dense and extensive, which explains why Section 1, despite having more fractures, showed lower sand production.

The simulation results were found to be in good agreement with available field observations, including mud-loss data and the reported production of solid particles. This validation confirms the reliability of the integrated DEM approach for predicting sand production in wells with pre-existing fractures.

From a practical standpoint, our study provides a powerful analytical framework for the simultaneous optimisation of hydraulic fracturing design and sand-production management in moderately cemented sandstone reservoirs. Engineers can use this approach to assess different stimulation scenarios prior to field execution, thereby reducing the risk of sanding.

Future work should extend this analysis to include the effects of fracture orientation, production rate, fluid properties, and proppant placement, using coupled CFD-DEM models. Moreover, the influence of chemical degradation (e.g., CO_2-induced acidification) on bond strength and sand production should be investigated, as this could further improve the predictive capability of the model.

4. Reference

[1] Duran, O., Sanei, M., Devloo, P. R. B., et al. (2020). An enhanced sequential fully implicit scheme for reservoir geomechanics. Computational Geosciences, 24, 1557–1587. DOI: 10.1007/s10596-020-09954-1

[2] Sanei, M., Duran, O., Devloo, P. R. B., & Santos, E. S. R. (2021). Analysis of pore collapse and shear-enhanced compaction in hydrocarbon reservoirs using coupled poro-elastoplasticity and permeability. Arabian Journal of Geosciences, 14(7). DOI: 10.1007/s12517-021-07081-2

[3] Nouri, A., Kuru, E., & Vaziri, H. (2009). Elastoplastic modelling of sand production using fracture energy regularization method. Journal of Canadian Petroleum Technology, 48(4), 64–71. DOI: 10.2118/09-04-64

[4] Bianco, L. C., & Halleck, P. M. (2001). Mechanisms of sand production: An experimental study. SPE International Symposium on Oilfield Chemistry. DOI: 10.2118/65009-MS

[5] Fjaer, E., Holt, R. M., Horsrud, P., Raaen, A. M., & Risnes, R. (1992). Petroleum related rock mechanics.

[6] Yazdani, M., Fatehi Marji, M., Najafi, M., & Sanei, M. (2025). Simulating the hydraulic fracturing mechanism around the hydrocarbon wellbores with emphasizing its effects on the sand production. Journal of Mining and Environment, 16(1), 241–258.

[7] He, Q., Suorineni, F. T., & Oh, J. (2016). Review of hydraulic fracturing for preconditioning in cave mining. Rock Mechanics and Rock Engineering, 49(12), 4893–4910. DOI: 10.1007/s00603-016-1028-2

[8] Nadimi, S., Miscevic, I., & McLennan, J. (2016). A 3D peridynamic simulation of hydraulic fracture process in a heterogeneous medium. Journal of Petroleum Science and Engineering, 145, 444–452. DOI: 10.1016/j.petrol.2016.06.001

[9] Shi, L.-Y. (2023). Hydraulic fracture propagation in rock mass with XFEM. Soil Mechanics and Foundation Engineering, 60(5), 436–443. DOI: 10.1007/s11204-023-09915-1

[10] Zeerak, M. R., Fatehi Marji, M., Sanei, M., Najafi, M., & Abdollahipour, A. (2026). Numerical modeling of hydraulic fracturing for crack growth mechanism investigation in rocks using XFEM with a BEM-based verification. Journal of Mining and Environment, 17(2), 717–742.

[11] Cundall, P. A., & Strack, O. D. L. (1979). A discrete numerical model for granular assemblies. Géotechnique, 29(1), 47–65.

[12] Potyondy, D. O., & Cundall, P. A. (2004). A bonded-particle model for rock. International Journal of Rock Mechanics and Mining Sciences, 41(8), 1329–1364. DOI: 10.1016/j.ijrmms.2004.09.011

[13] Sanei, M., Durán, O., Devloo, P. R. B., & Santos, E. S. R. (2022). Evaluation of the impact of strain-dependent permeability on reservoir productivity using iterative coupled reservoir geomechanical modeling. Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 54(2). DOI: 10.1007/s40948-022-00390-2

[14] Itasca Consulting Group, Inc. (2019). PFC — Particle Flow Code, Ver. 7.0 [Computer software]. Itasca.

[15] Joodi, B., Sarmadivaleh, M., Rasouli, V., & Nabipour, A. (2012). Simulation of the cutting action of a single PDC cutter using DEM. WIT Transactions on Engineering Sciences, 81, 143–150. DOI: 10.2495/PMR120141

[16] Gu, C., Li, X., Zou, Y., Feng, Y., Sanei, M., Yan, W., & Mosleh, M. H. (2025). Integrating mechanical and chemical perspectives: Assessing and enhancing cement sheath integrity in CO_2 geological storage wells. Journal of Rock Mechanics and Geotechnical Engineering. DOI: 10.1016/j.jrmge.2025.11.006