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# Fine particle liberation in saturated porous media under non-isothermal-fluid flow

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Decline in well productivity is a widely reported phenomenon and a critical challenge negatively impacting energy and water operations in deep geological reservoirs [1, 2]. A key contributor to this problem is the detachment of in-situ fine particles present in the porous matrix, which will then migrate and travel through the porous formation until getting strained within thin pore throats resulting in pore clogging and therefore permeability damage [3]. The detachment of in-situ fine particle occurs when the mechanical equilibrium of the attaching (i.e., electrostatic and gravity forces) and the detaching forces (i.e., drag and lifting forces) exerted on the particle is disturbed. In geological reservoirs, the equilibrium of in-situ fines can be disturbed as a result of fluid flow velocities, temperature alterations in the porous formation, or reduced ionic strength of the in-situ fluids [4]. Fines migration and straining can also alter in-situ stresses through generating pore pressure changes as a result of permeability damage [5].

Multiple experimental and numerical studies have evaluated the mechanisms involved in detachment, migration, and straining of in-situ fines and the clogging of pore fluid channels [6, 7]. A number of studies have also focused on evaluating temperature-induced particle mobilization [8]. Variations of the electrostatic force with temperature is often explained through the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory [9]. In a saturated porous formation containing in-situ fines, Dielectric permittivity of pore fluid decreases with an increase in temperature, weakening the repulsion between the fine clay particles and the sand surface [10]. As a result, the attaching electrostatic forces are lower under higher temperatures.

This study focuses on developing a theoretical model to evaluate the impact of the size distribution of in-situ fine particles on non-isothermal fluid flow induced fine mobilization in saturated porous media. Expressions for drag force and electrostatic force are obtained based on the DLVO theory considering coupled effects of fluid velocity, temperature, and ionic strength of in-situ fluids. The main parameters adopted in the proposed model are presented in Table 1. The proposed model predicts the maximum concentration of retained fines considering coupled effects from temperatures and pore pressures. Results are valuable for estimating permeability damage and well productivity during enhanced geothermal operations.

**Table 1: Model parameters.**

| **Parameter explanations** | **Parameter symbols and units** |
|---|---|
| Boltzmann constant | $k_B$ , $J/K$ |
| Static dielectric constant of fines at initial temperature | $\varepsilon_{10}$ |
| Static dielectric constant of solid skeleton | $\varepsilon_2$ |
| Refractive index of fines | $n_1$ |
| Refractive index of solid skeleton at initial temperature | $n_{20}$ |
| Salt concentration | $c_n$ , $mol/L$ |
| Mass percent of salt | $x$ |
| Absorption frequency | $v_e$ , $1/s$ |
| Planck constant | $h$ , $J \cdot s$ |
| Characteristic wavelength of interaction | $\lambda$ , $nm$ |


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| | |
|---|---|
| Porosity | $\phi$ |
| Half-width of the channel | $H$ , $\mu m$ |
| Elementary electric charge | $e$ , $C$ |
| Avogadro constant | $N_A$ , $1/mol$ |
| The valence of ions | $z$ |
| Dielectric permittivity of vacuum | $\varepsilon_0$ , $F/m$ |
| Zeta potential of fines at initial temperature | $\zeta_{s0}^{f}$ , $mV$ |
| Zeta potential of solid skeleton at initial temperature | $\zeta_{s0}^{s}$ , $mV$ |
| Collision diameter | $\sigma_c$ , $nm$ |
| Mean particle size parameter | $d_g$ , $\mu m$ |
| Coefficients of size distribution | $m$ , and $n$ |
| lever arm ratio | $\varepsilon_p$ |

**Data Availability Statement**

Data associated with this research are available and can be obtained by contacting the corresponding author.

**Contributor statement**

Conceptualization: Xinle Zhai, Kamelia Atefi-Monfared; Data Calculation and Analysis: Xinle Zhai; Writing – Original Draft: Xinle Zhai, Kamelia Atefi-Monfared; Writing – Review & Editing: Kamelia Atefi-Monfared

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