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Artificial Intelligence-Assisted Matrix Acidizing Simulation of Oil and Gas Wells

Introduction

Acidizing is a critical stimulation technique in the oil and gas industry, employed to enhance hydrocarbon production from wells. This process involves injecting acid, typically hydrochloric acid (HCl) or other acid mixtures, into the wellbore and surrounding rock formations to dissolve minerals such as limestone, dolomite, or calcite. By improving reservoir rock permeability and creating flow channels, acidizing significantly boosts well productivity, particularly in carbonate reservoirs prone to scale buildup or formation damage. The technique not only increases recovery but also extends well life and reduces operational costs.

The integration of AI in acidizing simulations and scale-up processes presents transformative opportunities. AI models can analyze complex cases, predict acid-rock interactions, and optimize treatment designs for field-scale applications. By coupling machine learning with advanced simulation tools, operators can better model heterogeneous reservoir conditions, enhance the accuracy of performance forecasts, and minimize uncertainties in upscaling from core samples to field implementations. This fusion of AI with traditional techniques ensures more efficient, cost-effective, and sustainable acidizing operations.

Methodology

The upscaling process from core samples to field applications begins with detailed computational fluid dynamics (CFD) simulations conducted at the core level. These simulations provide insights into acid-rock interactions, flow dynamics, and reaction kinetics under controlled conditions. The resulting data is used to develop predictive models that account for reservoir heterogeneity and operational parameters. Advanced simulation tools and machine learning techniques are then employed to scale these findings to field-level applications, optimizing treatment designs while minimizing uncertainties. Validation against field data ensures the robustness and applicability of the scaled models, bridging the gap between core-scale insights and field-scale operations.

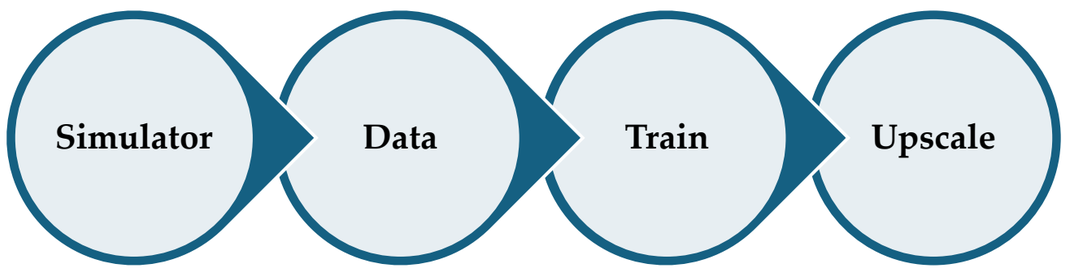

Figure 1: The methodology of upscaling process

Computational Fluid Dynamics (CFD) is a powerful tool for simulating fluid flow, chemical reactions, and transport phenomena, widely used in engineering and scientific research. It allows detailed analysis of complex processes, such as acid-rock interactions in reservoir simulations. OpenFOAM, an open-source CFD platform, provides a versatile framework for solving partial differential equations governing fluid dynamics and reactions.

Table 1: Core simulation parameters

Symbol	Parameter	Unit	Symbol	Parameter	Unit
ϵ	Porosity	-	K_s	Reaction Rate Const.	m/s
ρ	Density	kg/m^3	K_c	Mass Transfer Coeff.	m/s
U	Velocity	m/s	α	Dissolving Power	-
μ	Viscosity	$pa.s$	a_V	Surface per Volume	$1/m$
P	Pressure	pa	r	Pore Radius	m
K	Permeability	m^2	t	Time	$sec.$
C	Concentration	kg/m^3	D_e	Diffusion	m^2/s

Momentum
$$\frac{1}{\varepsilon}\left(\frac{\partial \rho U}{\partial t} + \nabla.\left(\frac{\rho}{\varepsilon}UU\right)\right) = \frac{\mu}{\varepsilon}\nabla^2 U - \nabla P + \rho g - \frac{\mu}{K}U$$

Continuity
$$\frac{\partial \varepsilon}{\partial t} + \nabla.U = 0$$

Acid species balance
$$\frac{\partial(\varepsilon C_f)}{\partial t} + \nabla.(UC_f) = \nabla.(\varepsilon D_e.\nabla C_f) - K_c a_V (C_f - C_s)$$

Solid phase
$$\frac{\partial \varepsilon}{\partial t} = \frac{R(C_s) a_V \alpha}{\rho_s}$$

Mass transfer
$$K_c(C_f - C_s) = R(C_s)$$

Reaction
$$R(C_s) = K_s C_s$$

Permeability
$$\frac{K}{K_0} = \frac{\varepsilon}{\varepsilon_0}\left(\frac{\varepsilon(1-\varepsilon_0)}{\varepsilon_0(1-\varepsilon)}\right)^{2\beta}$$

Radius
$$\frac{r_p}{r_0} = \sqrt{\frac{K\varepsilon_0}{K_0\varepsilon}}$$

Surface Area
$$\frac{a_v}{a_0} = \frac{\varepsilon r_0}{\varepsilon_0 r_p}$$

Results

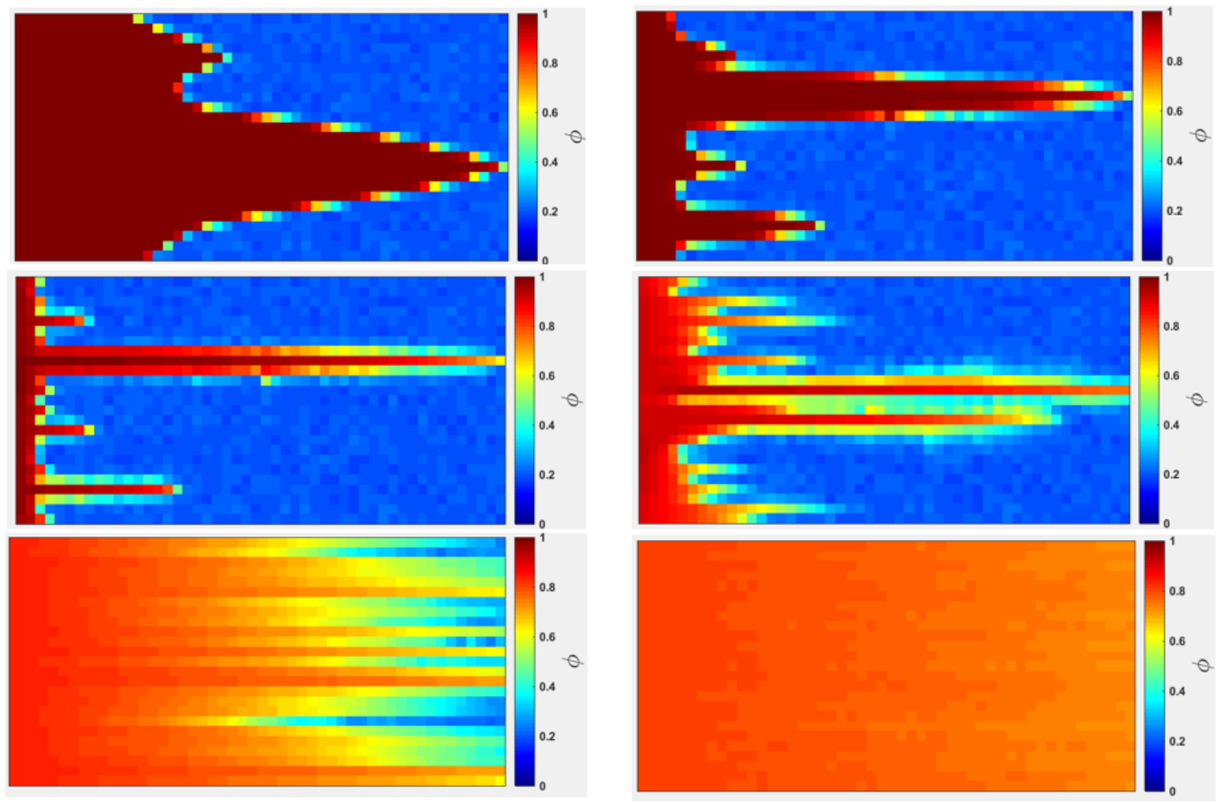

Figure 2: Different dissolution patters in core simulation

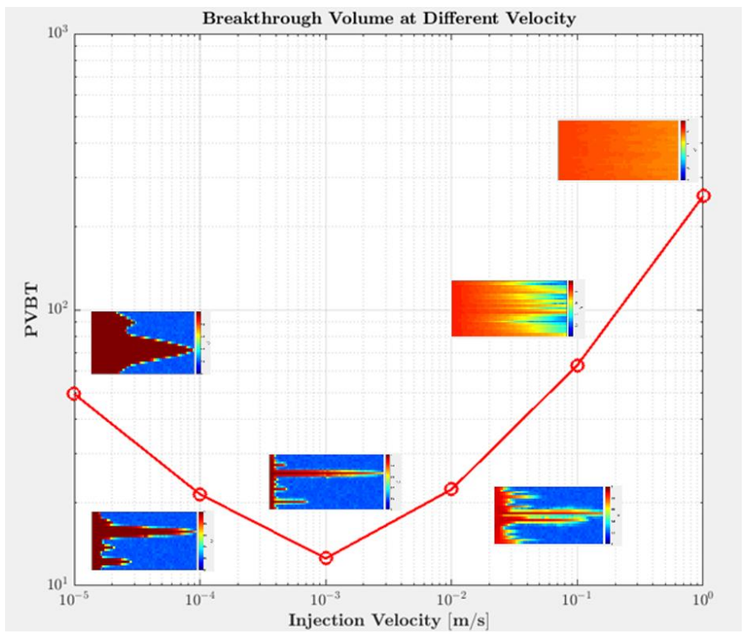

Figure 3: Breakthrough pore volume at varying injection velocities

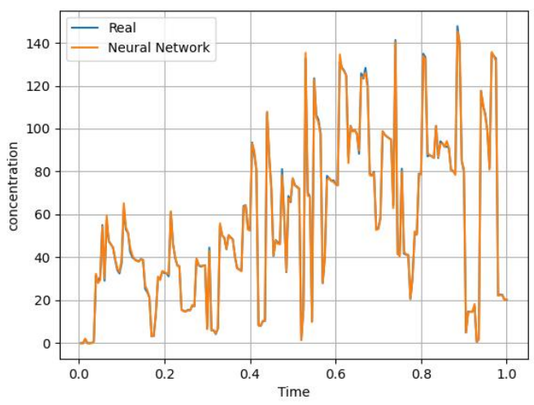

Figure 4: CFD vs model prediction for concentration

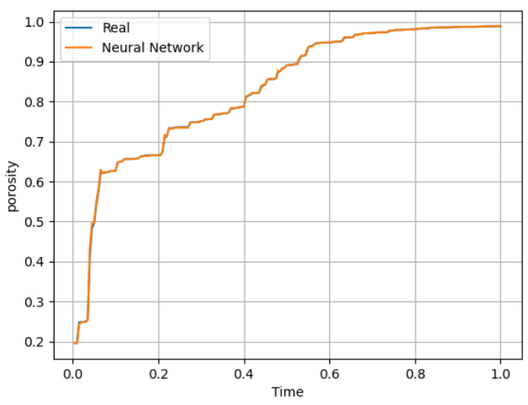

Figure 5: CFD vs model prediction for porosity

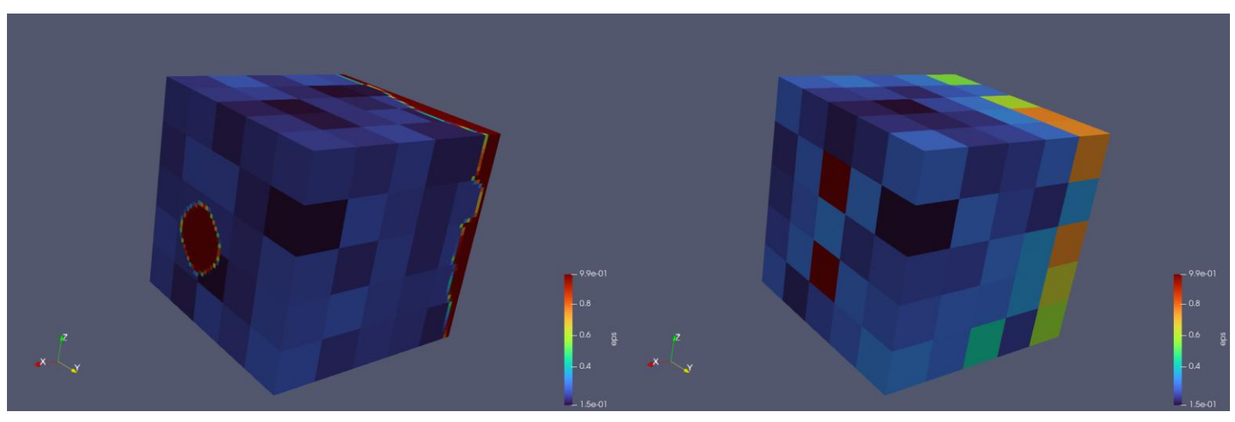

Figure 6: Comparing CFD and Model Upscaling Results in Porosity Estimation

Discussion

- Simulations have the capability to generate diverse dissolution patterns
- Core-scale simulations can be conducted within a reasonably manageable time
- The proposed model demonstrates the capability to predict results with a high degree of accuracy in core scale
- The upscaled results closely align with those obtained from CFD simulations
- The process is scalable and can be effectively applied to larger scales.