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Wormhole Geometry Modelling on Carbonate Matrix Acidizing: A Literature Review

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Abstract:- Matrix acidizing is a critical well-stimulation technique used to enhance the permeability of carbonate reservoirs by creating channels or "wormholes" through the dissolution of the rock matrix. The efficiency of this process is significantly influenced by the geometry of the wormholes formed. This review paper provides a comprehensive analysis of current research on wormhole geometry modeling in carbonate matrix acidizing, synthesizing findings from experimental studies, analytical models, and numerical simulations. Key factors affecting wormhole geometry, such as acid concentration, injection rate, and rock properties, are discussed. The review highlights the contributions of various modeling approaches in predicting wormhole formation and propagation, emphasizing the importance of accurately capturing the coupled effects of fluid flow, chemical reactions, and rock dissolution. The implications for optimizing acidizing treatments and enhancing hydrocarbon recovery are explored, alongside recommendations for future research. These include the need for field validation, advanced modeling techniques, real-time monitoring, interdisciplinary collaboration, and sustainability considerations. This synthesis aims to provide a foundation for improving the design and execution of matrix acidizing operations in carbonate reservoirs.

***Keywords**:- Wormhole Geometry, Carbonate Acidizing, Modeling Review.*

I. INTRODUCTION

One of the major issues in oil and gas production wells is their very low production rates. This can be attributed to low formation permeability and formation damage, which results in a positive and large skin factor (Burton et al., 2018). Formation damage refers to a region of decreased permeability in wells, leading to reduced performance (Liu et al., 2013). This damage can occur during drilling, cementing, workover operations, production, or even during acidizing and chemical treatments, followed by the plugging of pore throats (Liu et al., 2013; Mcleod, 1984).

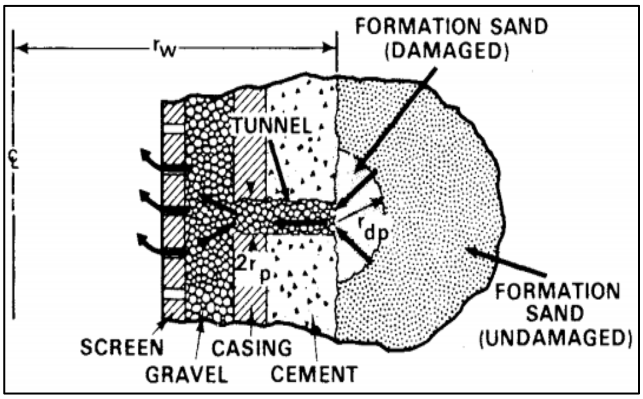


Fig 1 Gravel-Packed Tunnel with Collapsed Perforation (Mcleod, 1984).

To address this, well stimulation techniques such as matrix acidizing or hydraulic fracturing can be employed to increase well deliverability. The primary goal of well stimulation is to improve formation permeability (Panga et al., 2005). Matrix acidizing is a widely employed well-stimulation technique in the oil and gas industry, particularly for carbonate reservoirs (Fan et al., 2018; Mcleod, 1984). The primary goal of matrix acidizing is to improve the permeability of the reservoir by dissolving portions of the rock matrix, thus creating channels or "wormholes" that enhance fluid flow (Akanni, O O, Nasr-El-Din, 2015; Cheng et al., 2020). The efficiency of this process is heavily influenced by the geometry and evolution of these wormholes. Understanding and accurately modeling wormhole geometry is crucial for optimizing acidizing treatments and maximizing hydrocarbon recovery (Daccord et al., 1993). Wormhole formation and propagation are complex processes governed by various factors, including the properties of the acid, rock composition, injection rate, and reservoir conditions (Wang et al., 1993). Accurate models of wormhole geometry can provide valuable insights into the acidizing process, enabling better design and execution of stimulation treatments (Fredd et al., 1997; Fredd & Fogler, 1998; Fredd & Miller, 2000; Hoefner et al., 1987). This review aims to provide a comprehensive overview of current research on wormhole geometry modeling in carbonate matrix acidizing, highlighting key findings, methodologies, and future directions.

II. LITERATURE REVIEW

- *Fundamentals of Matrix Acidizing in Carbonates*

Matrix acidizing in carbonate reservoirs involves the injection of hydrochloric acid (HCl) or other acids into the reservoir rock (Buijse, 2000; Burton et al., 2018). Matrix acidizing is a widely used technique in the oil and gas industry to enhance well productivity. For a successful acidizing job, it is essential to fully understand the dissolution behavior of the formation rock with the injected acid (Pandey et al., 2018). The acid reacts with the carbonate minerals, primarily calcium carbonate, resulting in the dissolution of the rock and the creation of wormholes (Bekibayev et al., 2015; Fan et al., 2018; Pichler et al., 1992). These wormholes can significantly enhance the permeability of the rock by providing new flow pathways (Cheng et al., 2020). The efficiency of the matrix acidizing process in carbonates strongly depends on the wormholing phenomenon. If wormholes are formed, the effects of near-wellbore damage can be mitigated with a relatively small amount of acid (Huang et al., 1997).

- *Wormhole Formation and Propagation*

The mechanism of wormhole propagation has been extensively studied through experiments by numerous researchers (Buijse, 2000; Daccord et al., 1993; Fredd et al., 1997; Pichler et al., 1992; Wang et al., 1993). Natural fractures significantly influence flow fields, thereby affecting wormhole patterns during acidizing (Mou et al., 2019). Wormhole formation is influenced by the interplay of chemical reactions, fluid flow, and rock properties (Wang et al., 1993; Wei et al., 2023). Early studies by Economides & Frick (1994), Gong & El-Rabaa (1999) and Akanni & Nasr-El-Din (2016) laid the foundation for understanding the basic mechanisms of wormhole formation. They identified key parameters such as acid concentration, injection rate, and rock heterogeneity as critical factors affecting wormhole geometry.

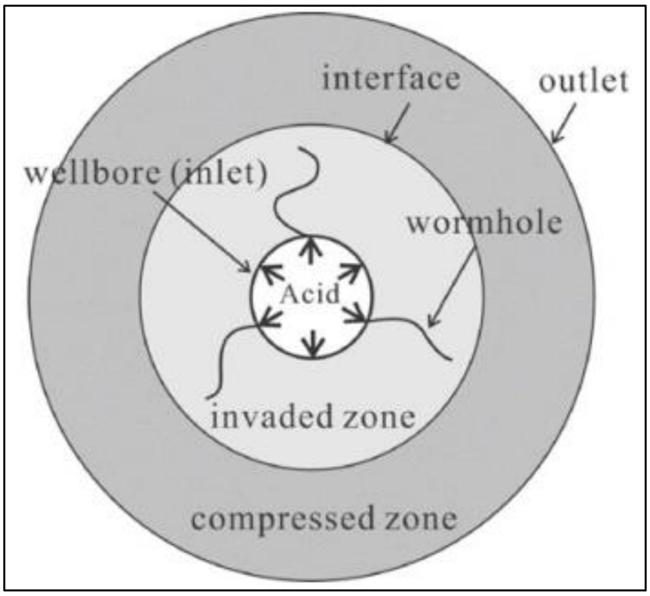


Fig 2 Schematic Diagram of Wormhole Propagation in Polar Coordinate (Liu et al., 2013).

- *Modeling Approaches*

Various approaches have been developed to model wormhole geometry, ranging from analytical models to numerical simulations. Analytical models, such as those proposed by Economides et al., (1994); Frick et al., (1994); Pichler et al., (1992); Zolotukhin & Frick, (1994) and Fredd & Fogler, (1998), provide simplified descriptions of wormhole propagation based on key parameters. These models have been useful for gaining initial insights but are often limited in their ability to capture the full complexity of the process. Numerical simulations offer a more detailed and comprehensive approach to modeling wormhole geometry (Golfier et al., 2001). Numerical simulation in a commercial computational fluid dynamics (CFD) package using finite volume method. Incorporation of heterogeneous porosity, permeability, and mineralogy in the modeling (De Oliveira et al., 2012). CFD and reactive transport modeling are commonly used techniques. For instance, Golfier et al., (2002) developed a numerical model that incorporates fluid flow, chemical reactions, and rock dissolution to simulate wormhole formation. Their work demonstrated the importance of considering the coupled effects of these processes to accurately predict wormhole geometry.

- *Factors Influencing Wormhole Geometry*

Several factors influence the geometry and effectiveness of wormholes in carbonate acidizing. These include:

- Acid type and concentration: Different acids and concentrations can result in varying reaction rates and dissolution patterns (Fredd & Fogler, 1998; Huang et al., 1999).
- Injection rate: The rate at which acid is injected influences the balance between dissolution and fluid flow, affecting wormhole branching and propagation (Wang et al., 1993).
- Rock properties: Heterogeneity in rock composition and structure can lead to irregular wormhole patterns and impact the overall effectiveness of acidizing (Bazin, 1998).

III. RESEARCH METHOD

- *Data Collection and Analysis*

This review synthesizes findings from experimental studies, analytical models, and numerical simulations related to wormhole geometry in carbonate acidizing. Relevant articles were sourced from scientific databases such as Scopus and Onepetro, using keywords like wormhole geometry, carbonate matrix acidizing, and reactive transport modeling. Studies from 1984 to 2023 were included to capture the evolution of research in this field.

- *Comparative Analysis*

The collected studies were analyzed to compare different modeling approaches and identify key factors influencing wormhole geometry. Statistical methods, qualitative method and review method, were used to analyse the impact of various parameters on wormhole formation and propagation.

- *Previous Research*

List of various previous studies on wormhole geometry, carbonate matrix acidizing, and reactive transport modeling as shown in Table 1.

IV. RESULTS

- *Key Findings from Experimental Studies*

Experimental studies have provided valuable insights into the physical characteristics of wormholes. For instance, Burton et al., (2018) conducted laboratory experiments using X-ray computed tomography (CT) to visualize wormhole development in real-time. Their findings highlighted the importance of acid injection rate and concentration in controlling wormhole morphology. Based on laboratory and design studies, Williams et al. (1979) recommended using 50 to 200 gallons per foot of 28% hydrochloric acid (HCl) acid for carbonate matrix treatment. CT has become a standard method for characterizing wormholes. In this study, a slightly different experimental setup was used to observe wormhole propagation with 15% HCl acid without any additives. To acquire a sequence of CT images while injecting fluids into a linear core, the core holder was rotated as shown in Figure 3. All laboratory details are summarized in Table 2.

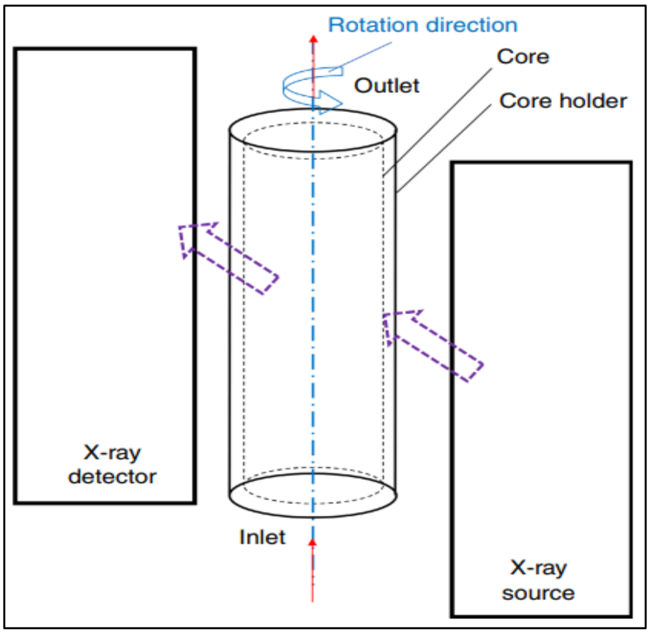
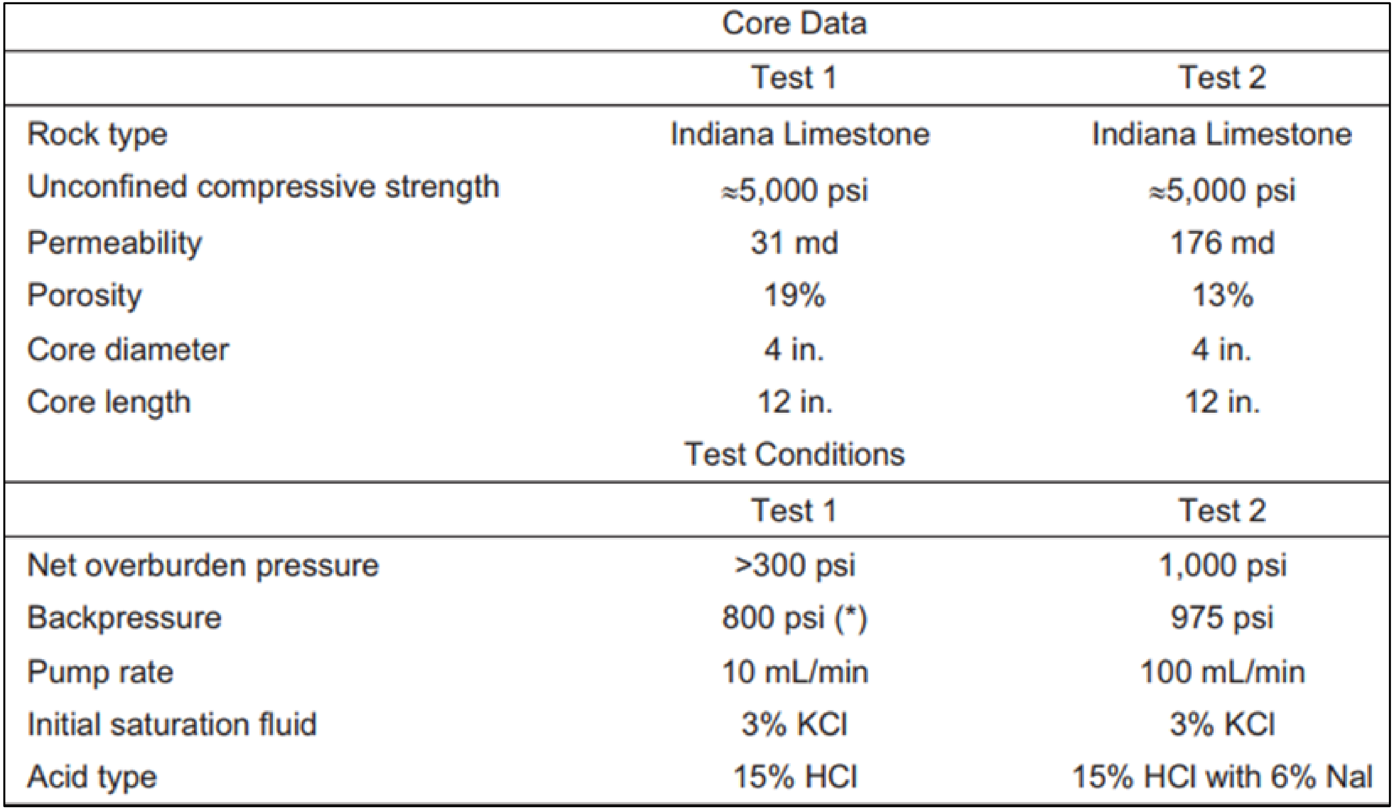


Fig 3 Coreflooding Setup with Real-Time CT Scanning (Burton et al., 2018).

Table1 Real-Time CT-Scanning Coreflooding Test Conditions (Burton et al., 2018)



Core Data		
	Test 1	Test 2
Rock type	Indiana Limestone	Indiana Limestone
Unconfined compressive strength	≈5,000 psi	≈5,000 psi
Permeability	31 md	176 md
Porosity	19%	13%
Core diameter	4 in.	4 in.
Core length	12 in.	12 in.
Test Conditions		
	Test 1	Test 2
Net overburden pressure	>300 psi	1,000 psi
Backpressure	800 psi (*)	975 psi
Pump rate	10 mL/min	100 mL/min
Initial saturation fluid	3% KCl	3% KCl
Acid type	15% HCl	15% HCl with 6% NaI

Figure 4 displays a real-time 2D CT scan image and a 3D CT image created by compiling a series of 2D CT images following the core flooding test. The use of 6% NaI enhanced the CT-number contrast between the core matrix and the wormholes, as illustrated in Figure 5. The first four images from the left are real-time 2D CT scans, with the blue lines indicating the wormholes.

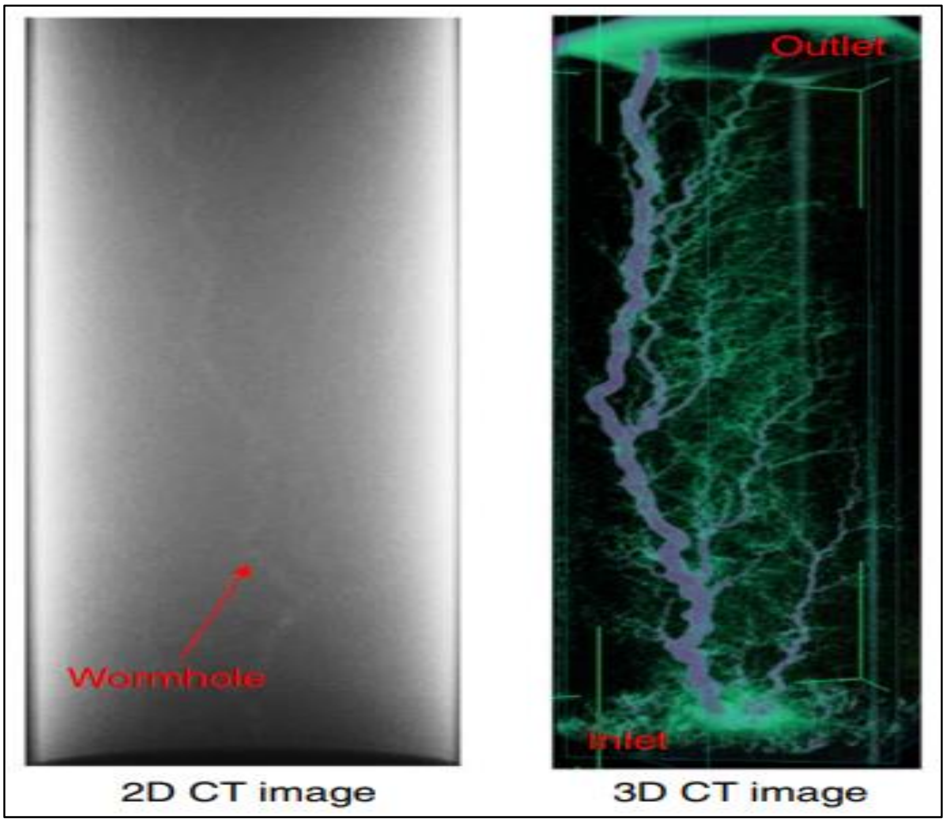


Fig 4 CT Images: A Real-Time CT Image Obtained while Pumping Acid (Left) and a 3D CT Image Obtained by Compiling a Series of 2D Images (Right) in Test 1 (Burton et al., 2018).

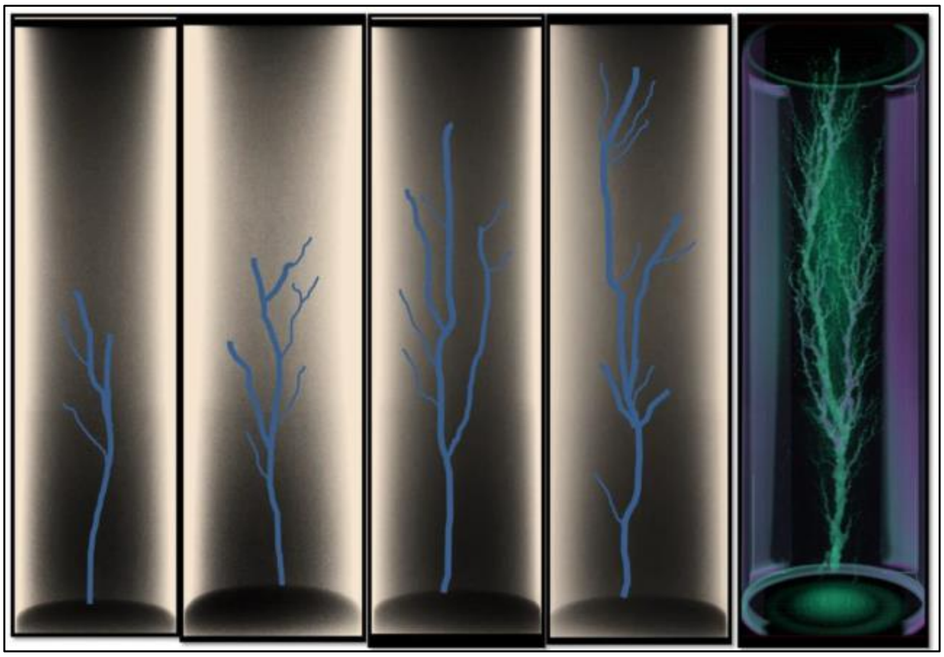
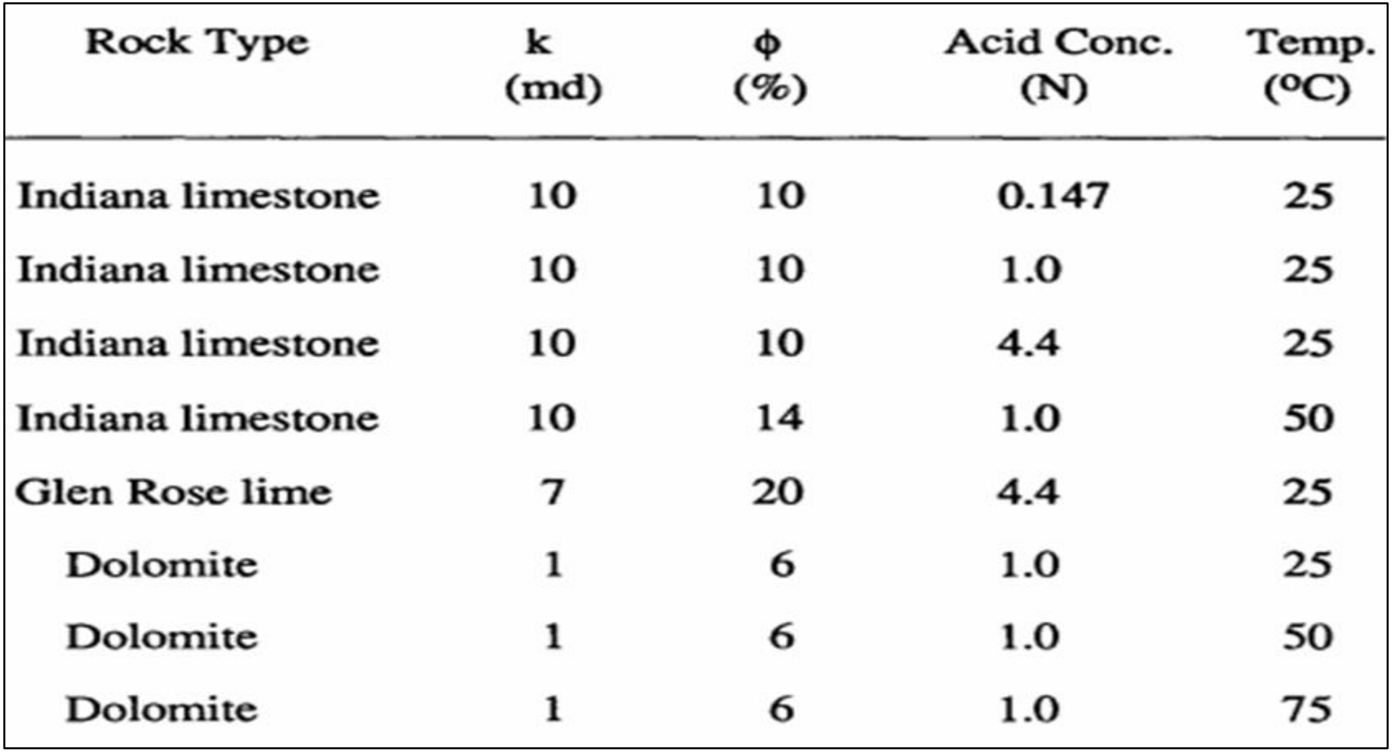


Fig 5 CT Images: A Real-Time CT Image Obtained while Pumping Acid (Left) and a 3D CT Image Obtained by Compiling a Series of 2D Images (Right) in Test 2 (Burton et al., 2018).

- *Insights from Analytical Models*

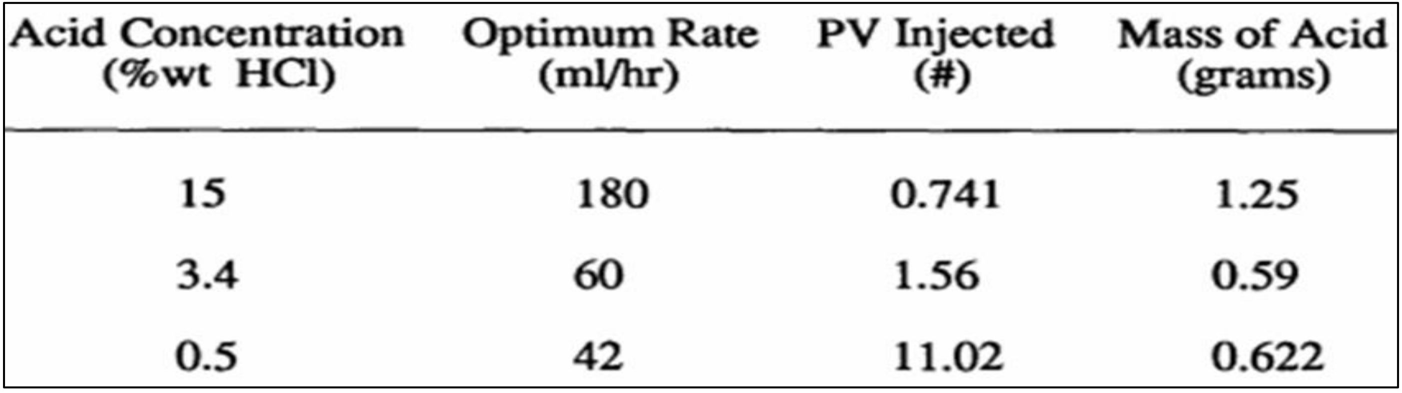
Analytical models have contributed to understanding the fundamental principles governing wormhole formation. Wang et al., (1993) developed a model predicting the optimum injection rate for maximizing wormhole penetration, emphasizing the trade-off between dissolution and fluid flow. Fredd & Fogler (1998) extended this work by incorporating the effects of acid concentration and reaction kinetics. Wang et al., (2007) conducted laboratory coreflood experiments with dolomite and two types of limestone, Indiana and Glen Rose, to simulate reservoir acidizing conditions. All core samples were 1 in. in diameter and five or six in.

Table 2 Experimental Conditions (Wang et al., 1993).



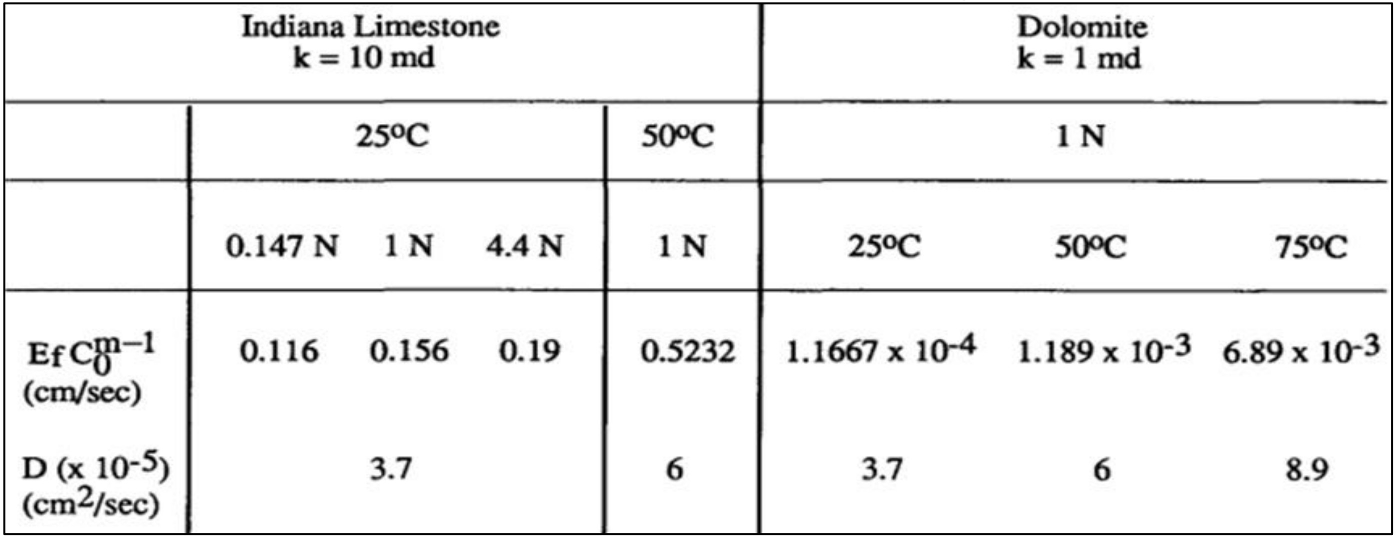
Rock Type	k (md)	ϕ (%)	Acid Conc. (N)	Temp. (°C)
Indiana limestone	10	10	0.147	25
Indiana limestone	10	10	1.0	25
Indiana limestone	10	10	4.4	25
Indiana limestone	10	14	1.0	50
Glen Rose lime	7	20	4.4	25
Dolomite	1	6	1.0	25
Dolomite	1	6	1.0	50
Dolomite	1	6	1.0	75

Table 3 The Optimum Injection Rates and the Corresponding Amount of Acid Injected to Penetrate the Core of 1" Diameter x 6" Length at Different Acid Concentrations (Wang et al., 1993).



Acid Concentration (%wt HCl)	Optimum Rate (ml/hr)	PV Injected (#)	Mass of Acid (grams)
15	180	0.741	1.25
3.4	60	1.56	0.59
0.5	42	11.02	0.622

Table 4 The Experimental Conditions Used in the Model (Wang et al., 1993).



	Indiana Limestone k = 10 md				Dolomite k = 1 md		
	25°C			50°C	1 N		
	0.147 N	1 N	4.4 N	1 N	25°C	50°C	75°C
$E_f C_0^{m-1}$ (cm/sec)	0.116	0.156	0.19	0.5232	1.1667×10^{-4}	1.189×10^{-3}	6.89×10^{-3}
D ($\times 10^{-5}$) (cm^2/sec)	3.7			6	3.7	6	8.9

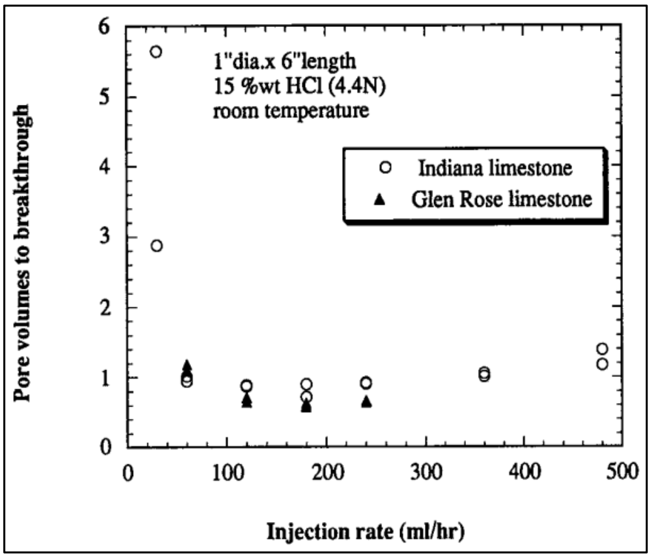


Fig 6 Coreflood Results for Indiana and Glen Rose Limestones (Wang et al., 1993).

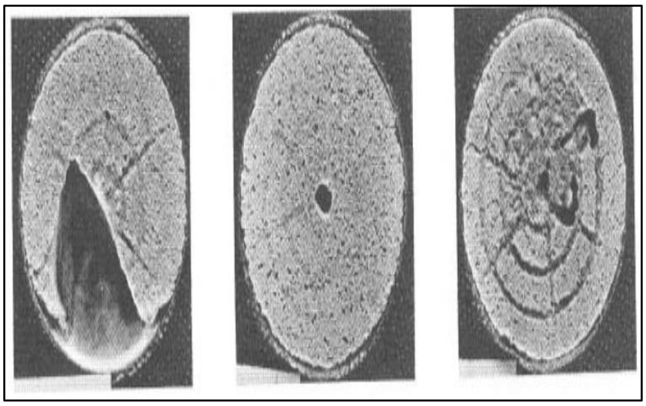


Fig 7 Inlet Flow Faces of Acidized Indiana Limestones Cores. Injection Rates (from Left to Right): 30 ml/hr, 180 ml/hr, and 480 ml/hr, 4.4 N HCL (15 wt %) and Room Temperature (Wang et al., 1993).

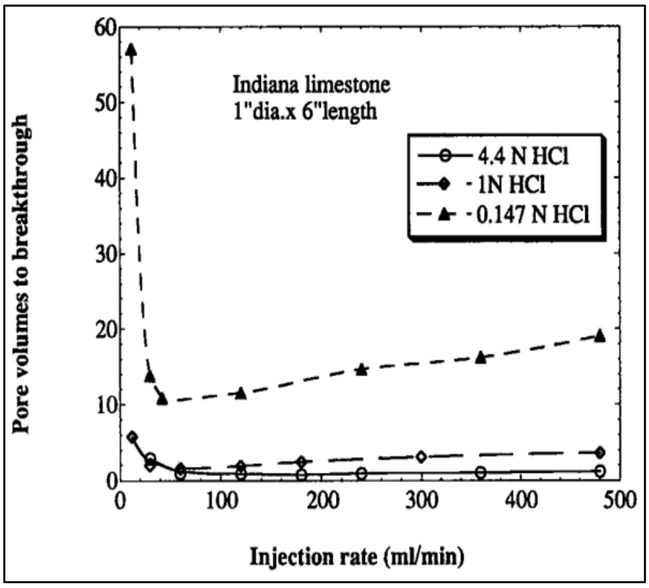


Fig 8 Coreflood Results at Different Acid Concentrations (Wang et al., 1993).

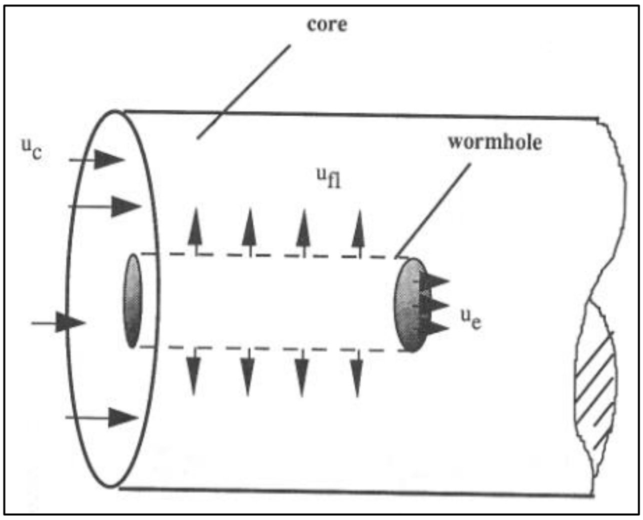


Fig 9 Schematic of Acid Flux Distribution (Wang et al., 1993).

- *Advances in Numerical Simulations*

Golfier et al., (2002) developed a reactive transport model that simulates the coupled effects of fluid flow, chemical reactions, and rock dissolution. Numerical simulations have advanced the ability to predict complex wormhole geometries under various conditions (Liu et al., 2013). Their simulations showed that wormhole geometry is highly sensitive to injection rate and rock heterogeneity (Liu et al., 2013). In Fig. 10, dissolution patterns for the two different porosity distribution methods are depicted at the optimal injection velocity. In both scenarios, the acid preferentially flows into the larger pores, forming wormholes (Liu et al., 2013).

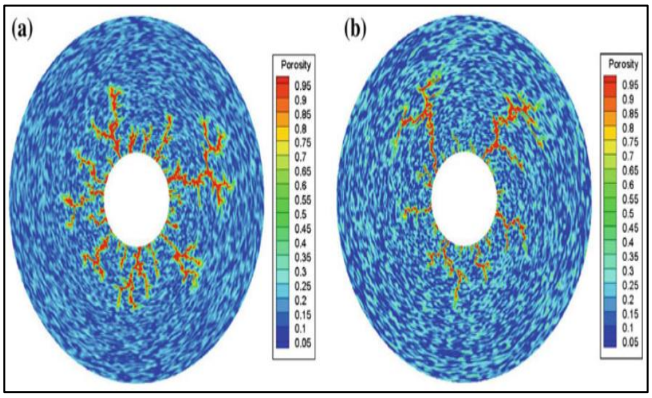


Fig 10 Dissolution Patterns Visible in Porosity Contour Plots at the Optimal Injection Velocity for a Uniformly Distributed Porosities and b Normally Distributed Porosities (Liu et al., 2013).

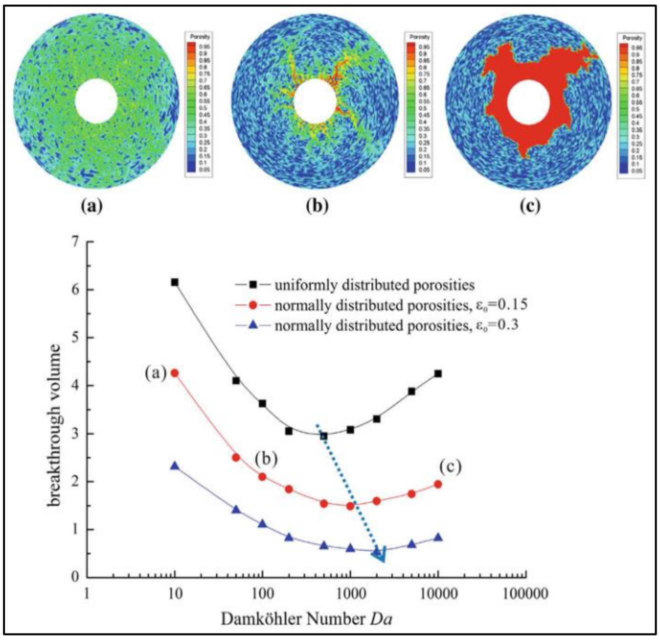


Fig 11 Breakthrough Curves for the Two Different Porosity Generation Methods: **a** Uniform Dissolution, **b** Ramified Wormholes, and **c** Face Dissolution (Liu et al., 2013).

Fig. 11 illustrates that the optimal Damköhler number rises with increasing heterogeneity. For uniformly distributed porosities, the optimal Damköhler number is 500. For normally distributed porosities, the optimal Damköhler numbers are 1,000 at $\varepsilon_0 = 0.15$ and 2,000 at $\varepsilon_0 = 0.3$. As the Damköhler number is inversely proportional to injection velocity, greater heterogeneity results in a lower optimal injection velocity. As the injection velocity decreases, dissolution patterns transition from uniform dissolution (Fig. 11a) to ramified wormholes (Fig. 11b), dominant wormholes (Fig. 10b), and finally to face dissolution (Fig. 11c).

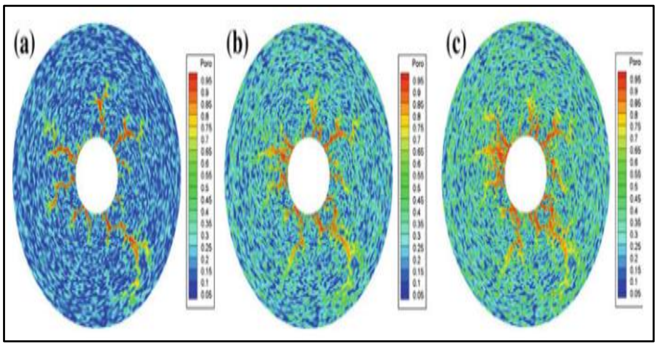
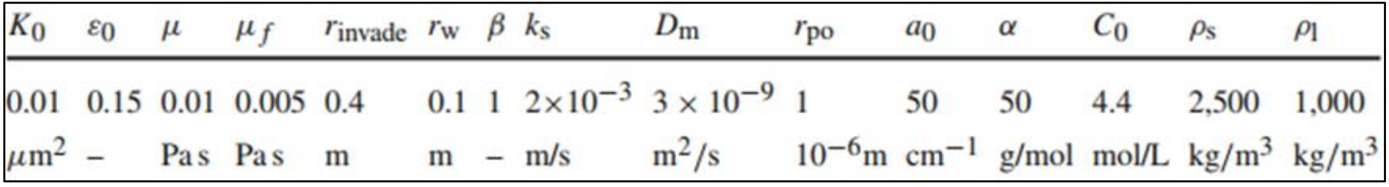


Fig 12 Dissolution Patterns in High Permeability Layer at **a** $K_{0h}/K_{0l} = 1$, **b** $K_{0h}/K_{0l}=4$, and **c** $K_{0h}/K_{0l}=8$ (Liu et al., 2013).

Fig. 12. Thus, a point of equilibrium exists between the wormholing effect and the compressed zone effect when the permeability ratio reaches a specific value. Using Eq. (1), permeabilities and porosities are calculated based on the initial average permeability and porosity listed in Table 6. The permeability ratio, K_{0h}/K_{0l}, is defined as the ratio of high permeability to low permeability, set at 10 × 10−3 μm². Liu et al., (2013) model various permeability ratios ranging from one to ten to account for the significant heterogeneity in carbonate reservoirs.

$$k = \frac{\varepsilon}{\varepsilon 0}\left(\frac{\varepsilon}{\varepsilon 0}\left(\frac{1-\varepsilon 0)}{1-\varepsilon}\right)\right)^{2\beta} \qquad (1)$$

Table 1 Model Parameters and Corresponding Values (Liu et al., 2013)



K_0	ε_0	μ	μ_f	r_{invade}	r_{w}	β	k_s	D_{m}	r_{po}	a_0	α	C_0	ρ_s	ρ_l
0.01	0.15	0.01	0.005	0.4	0.1	1	2×10^{-3}	3×10^{-9}	1	50	50	4.4	2,500	1,000
μm^2	–	Pa s	Pa s	m	m	–	m/s	m^2/s	10^{-6}m	cm^{-1}	g/mol	mol/L	kg/m^3	kg/m^3

Where;

a_0 = Initial average interfacial area per unit volume of the medium (m−1)

C_0 = Initial concentration of acid (mol L−1)

D_m = Molecular diffusivity (m 2 s−1)

K_0 = Initial average permeability of the medium (μm^2)

k = Dimensionless permeability of the medium

K_{0h} =Initial average permeability in the high permeability layer (μm^2)

K_{0l} = Initial average permeability in the low permeability layer (μm^2)

k_s = Surface reaction rate constant (m s−1)

α = Dissolving power of acid, defined as grams of solid dissolved per mole of acid reacted (g/mol)

P_I = Pressure at the interface between the invaded zone and the compressed zone (MPa)

β = Exponent determined from experiment

ε = Porosity of the medium

ε_0 = Initial average porosity of the medium

μ = Viscosity of the acid (mPa s)

μ_f = Viscosity of the reservoir fluid (mPa s)

ρ_s = Density of the rock (g cm−3)

r_w = Wellbore radius (m)

r_{invade} = Radius of the invaded zone (m)

r_{po} = Initial average pore radius (m)

V. DISCUSSION

➢ *Implications for Matrix Acidizing Design*

The findings from experimental studies, analytical models, and numerical simulations have significant implications for designing matrix acidizing treatments. Understanding the factors influencing wormhole geometry allows for better control of the acidizing process, leading to more effective stimulation and improved hydrocarbon recovery.

➢ *Limitations and Future Research*

While significant progress has been made in modeling wormhole geometry, several limitations remain. Most models rely on assumptions that may not fully capture the complexity of real-world conditions. Additionally, the impact of long-term acidizing operations on wormhole stability and reservoir performance requires further investigation.

➢ *Future Research should Focus on:*

- Field validation: Conducting field-scale studies to validate the applicability of existing models under real reservoir conditions.
- Advanced modeling techniques: Developing more sophisticated models that integrate machine learning and artificial intelligence to predict wormhole geometry more accurately.
- Multiphase flow: Exploring the effects of multiphase flow on wormhole formation and evolution in carbonate reservoirs.

VI. CONCLUSIONS AND RECOMMENDATIONS

➢ *Conclusions*

This review highlights the critical role of wormhole geometry in determining the success of carbonate matrix acidizing. Modeling efforts, ranging from analytical to numerical approaches, have provided valuable insights into the factors influencing wormhole formation and propagation. Accurate prediction of wormhole geometry can significantly enhance the design and execution of acidizing treatments, leading to improved reservoir performance.

➢ *Recommendations*

- Integration of models: combine analytical and numerical models to leverage the strengths of both approaches for more comprehensive predictions.
- Real-time monitoring: invest in technologies for real-time monitoring of wormhole development during acidizing operations to allow for dynamic adjustments.
- Interdisciplinary collaboration: foster collaboration between geologists, engineers, and computer scientists to develop more robust models and innovative solutions for matrix acidizing challenges.
- Sustainability considerations: incorporate environmental and sustainability considerations into the design of acidizing treatments to minimize the ecological impact of acid use.

✓ *Nomenclature*

a_0 = Initial average interfacial area per unit volume of the medium (m−1)

C_0 = Initial concentration of acid (mol L−1)

D_m = Molecular diffusivity (m 2 s−1)

K_0 = Initial average permeability of the medium (μm^2)

k = Dimensionless permeability of the medium

K_{0h} = Initial average permeability in the high permeability layer (μm^2)

K_{0l} = Initial average permeability in the low permeability layer (μm 2)
k_s = Surface reaction rate constant (m s−1)

P_I = Pressure at the interface between the invaded zone and the compressed zone (MPa)

r_w = Wellbore radius (m)

r_{invade} = Radius of the invaded zone (m)

r_{po} = Initial average pore radius (m)

✓ *Greek Symbols*

α = Dissolving power of acid, defined as grams of solid dissolved per mole of acid reacted (g/mol)

β = Exponent determined from experiment

ε = Porosity of the medium

ε_0 = Initial average porosity of the medium

μ = Viscosity of the acid (mPa s)

μ_f = Viscosity of the reservoir fluid (mPa s)

ρ_s = Density of the rock (g cm^{-3})

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Table 6 Summary of Previous Research

No	**Author**	**Journal and Year of Publication**	**Tittle**	**Summarized Abstract**	**Summarized Introduction**	**Research Objective**	**Methods Used**	**Results**
1	Harry O. McLeod Jr	SPE-13752-PA, 1984	Matrix Acidizing	Specialized in well completion and stimulation for 9 years. Emphasizes quality control and successful acidizing components.	Focus on matrix acidizing in sandstone and carbonate formations. Discusses the importance of damage location and intensity for acidizing. Emphasizes the need for successful acidizing based on damage presence.	1. Investigate matrix acidizing treatments for limestone and sandstone formations. 2. Focus on gravel pack damage research and quality improvement in tunnels. 3. Analyze acid treatments for shale, low-permeability formations with care.	Transient analysis techniques on acid treatments for accurate data. Quality control during pumping: monitoring pressure response, diverting stages, and more. Gravel packing, squeeze packer, retrievable bridge plug for isolating perforated intervals.	Matrix acidizing is beneficial for damaged oil, gas, and water wells
2	Mark L. Hoefner, H. Scott Fogler,	Onepetro, JPT, 1987	Role of Acid Diffusion in Matrix Acidizing of	New microemulsion system enhances acid diffusion in	Focuses on matrix acidizing in carbonate	1. Investigate acid diffusion rates in	Investigated acid diffusion rate and its impact on	Microemulsion system enhances acid penetration

	Johan Sjoblom		Carbonates	carbonate matrix treatments. Microemulsion stimulates cores effectively with low injection rates. Investigates acid diffusion rate's impact on limestone matrix stimulation.	formations for enhanced productivity.	microemulsions for efficient matrix treatments. 2. Study the effects of diffusion on the acidizing process in carbonates.	limestone stimulation. Applied fracture-acidizing concepts to understand acid transport in channels.	and core stimulation efficiency. Acid diffusion rate affects limestone stimulation and injection rate requirements.
3	Thomas Pichler, T.P. Frick, and M.J. Economides, Mining U. Leoben, and Johann Nittmann	SPE 25004, 1992	Stochastic Modeling of Wormhole Growth in Carbonate Acidizing With Biased Randomness	Describes permeability driven fingering model with tunable noise. Discusses diffusion limited aggregation model for reproducing aggregation of diffusing particles. Introduces diffusion-limited aggregation model used in various applied science fields. Dielectric Breakdown Model developed to modify DLA for biased growth processes.	Stochastic model of wormhole growth in carbonate acidizing with randomness	1. Stochastic modeling of wormhole growth in carbonate acidizing. 2. Describing the permeability driven fingering model with tunable noise.	Stochastic growth model based on pressure field. Dielectric Breakdown Model (DBM) with tunable noise for modeling patterns. Calculation of local pressure gradients normalized for growth selection.	Describes permeability-driven fingering model with tunable noise. Addresses the stochastic nature of wormholing process in carbonate acidizing.
4	G. Daccord, R. Lenormand’ and 0. Lletard	Onepetro, SPE, 1993	Chemical Dissolution of a Porous Medium by a Reactive Fluid-L Model for the “Wormholing” Phenomenon	Quantitative model for 'wormholes' in porous medium with reactive fluid. Equivalent size parameter derived from Darcy's law. Simple dimensionless equation for	Describes flow properties of dissolution patterns in porous media. Focuses on 'wormholes' formed by reactive fluids in soluble porous mediums.	1. Quantitatively model flow properties of dissolution patterns in porous media. 2. Describe how wormholing patterns depend on physical	Experimental results on limestone-HCl systems to confirm findings. Study effect of parameters: permeability, sample size, and acid diffusivity. Physical arguments used	Experiments focused on diffusivity effects in Newtonian fluids. The study used a single parameter to characterize dissolution patterns.

				physical parameters.		parameters. 3. Study experimental results to derive simple dimensionless equations. 4. Characterize pattern properties using a single parameter, the equivalent size.	to interpret experimental results and derive equations.	
5	Y. Wang, A.D. Hill, and R.S. Schechter	SPE 26578, 1993	The Optimum Injection Rate for Matrix Acidizing of Carbonate Formations	Paper discusses optimum acid injection rate for carbonates in core floods.	Focus on determining the optimum acid injection rate for carbonates. Resolving the conflict between high and low acid injection rates. Theoretical prediction of acid flux in linear cores. Addressing the complexity of dissolution patterns in carbonate formations. Discovering the practical implications of the optimum acid injection rate.	1. Resolve the existence of an optimum acid injection rate experimentally. 2. Develop a theoretical prediction of acid flux in linear cores. 3. Provide observations useful for practitioners stimulating carbonate formations.	Developed a theoretical prediction of acid flux in linear cores. Discovered an optimum acid injection rate for acid breakthrough.	Optimum acid injection rate for breakthrough in linear core floods. High rates lead to multiple wormholes, low rates result in surface spending. Acid flux prediction theory agrees with experimental results.
6	M.J. Economides and T.P. Frick	SPE 22334 PA, 1994	Optimization of Horizontal Well Matrix Treatments	Presents optimization method for horizontal well matrix stimulation. NPV used as an economic	Focus on optimizing matrix stimulation of horizontal wells for economic value.	1. Optimize horizontal well matrix treatments using net present value (NPV). 2. Balance	Optimization method for horizontal well matrix stimulation using NPV. Matrix stimulation in	Formation damage is not radial or evenly distributed in horizontal wells. Skin effect

				criterion for completion design optimization.	Discusses reservoir selection, productivity issues, and matrix stimulation importance. Describes formation damage distribution and the impact on horizontal well performance.	well segment lengths with stimulation fluid coverage for optimization.	horizontal wells using coiled tubing and acid.	from formation damage significantly impacts horizontal well performance. Matrix stimulation with coiled tubing is effective in horizontal wells. Partial stimulation design evaluation is crucial due to total damage removal impossibility.
7	Thomas P. Frick, Michael Kurmayr, and Michael .I. Economides	SPE 23789 PA, 1994	Modeling of Fractal Patterns in Matrix Acidizing and Their Impact on Well Performance	Model studies wormholes in carbonate acidizing for well performance analysis. Fractal patterns in wormholes quantified for post-treatment skin effect.	Describes fractal wormholes in carbonate acidizing and their well performance.	1. Study wormholes in carbonate acidizing and their impact on well performance. 2. Develop model to quantify wormhole shape, extent, and post-treatment skin effect. 3. Analyze acid volume, injection rate, fractal dimension, porosity, and permeabilities.	Model considers fractals, wormholes, acid volume, porosity, and permeabilities. Identifies fractal wormhole patterns, quantifies skin effect, and reaction kinetics	Model considers wormholes as fractals, studying acid volume, injection rate. Post-treatment skin effects developed for vertical and horizontal wells. Fractal patterns in carbonate formations quantified for well performance. Impact of acid injection rate on post-treatment skin effect analyzed.
8	M.J. Economldes, T.P. Frick and J. Nlttman	SPE 27409 PA, 1994	Enhanced Visualization of Acid/Carbonate Rock Interaction	Visualization of acid-carbonate rock interaction using stochastic models	Focuses on acid-rock reaction patterns in carbonate rocks for visualization.	1. Visualize and study reaction patterns between acid and carbonate rocks.	Diffusion-limited aggregation model. Dielectric breakdown model.	Simulation results show dominant wormholes in linear cores. Linear core experimental

					Discusses the need for stimulation in wells drilled in carbonate reservoirs.	2. Simulate growth of wormholes to assess variables and their impact. 3. Develop stochastic models for 3D simulation of wormhole growth.	2D and 3D PDF stochastic models.	results may not apply to radial environments. Stochastic models visualize wormhole growth between acids and carbonate rocks.
9	A.B. Zolotukhin and T.P, Frick	SPE 27017, 1994	A Mobility Driven Fingering Approach to the Field-Scale Simulation of Oil Recovery	Paper on mobility-driven fingering approach for oil recovery simulation. Stochastic models used for field-scale simulations based on reservoir properties.	Paper explores mobility-driven fingering model for oil recovery simulations.	1. Study instability phenomena in oil displacement due to formation heterogeneity. 2. Analyze the effect of mobility ratio on finger propagation in reservoirs. Investigate the impact of mobility ratios on sweep efficiency in flooding	Mobility driven fingering model (MDF) introduced for flooding performance simulation. Stochastic approach, PDF model, phase mobilities estimated by harmonic mean. Self-similarity of fractal objects used for upscaling in reservoir engineering.	Introduces mobility driven fingering model for flooding performance simulation. Fractal objects exhibit self-similarity, aiding upscaling in reservoir engineering.
10	C.N.Fredd, R. Tjia, H.S. Fogler	SPE 38167, 1997	The Existance of an Optimum Damkohler Number for Matrix Stimulation of Carbonte Formations	Effective matrix stimulation treatments rely on the formation of dominant wormhole channels.	The flow and reaction of acids in carbonate porous media results in the formation of highly conductive fow channels or wormholes. The structure of these wormholes is strongly dependent upon the injection rate and the fluid/rock properties	This study extends the investigation of chelating agents of the aminopolycarbocylic acid family as alternative stimulation fluids.	Experiment: newtron radiography, and rotating disk experiment	Similar results were obtained for the weekly dissociating acetic acid. Result derived a generalized description of the dissolution phenomenon that includes the effects of convention, reactant transport, reversible surface reactions, and products transport. Dimensional

								analysis reveals a common dependence on the generalized Damkholer number for flow and reaction. This optimum Damkholer number occurs approximately 0.17 for a wide range of fluid/rock systems.
11	T. Huang, A. D. Hill and R. S. Schechter	SPE 37312, 1997	Reaction Rate and Fluid Loss: The Keys to Wormhole Initiation and Propagation in Carbonate Acidizing	The efficiency of the matrix acidizing process in carbonates depends strongly on the wormholing phenomenon – if wormholes are formed, the effects of near wellbore damage can be overcome with relatively small of acid.	These studies have also shown that the acidizing process is most efficient defined as the process that will enhance near-wellbore permeability to the greatest depth with the smallest volume of acid when the wormholing pattern develops.	This paper is to investigate and developed a theory of the wormholing process which predicts when the wormholing pattern is most efficiently created as a function of the acid flux and other treatment variables.	Laboratory linear core floods. This study developed a cylindrical flow model to represent the flow field around a wormhole propagating from a wellbore which illustrates how to translate laboratory results to field conditions.	In general, the lower the reaction rate (such as at low temperatures in dolomites or with weak acids in limestones), the lower the injection rate required, making it easier to propagate dominant wormholes under matrix treating conditions in the field.
12	C.N. Fredd, and H.S. Fogler	SPE 31074, 1998	Alternative Stimulation Fluids and Their Impact on Carbonate Acidizing	Investigated ethylenediamine-tetraacetic acid (EDTA) as an alternative stimulation fluid for carbonate formations. EDTA can effectively wormhole in limestone at low injection rates. EDTA does not induce asphaltic sludge precipitation from crude oil.	Paper explores EDTA as an alternative fluid for carbonate acidizing. Investigates wormholing in limestone and sludge prevention with EDTA	1. Investigate the impact of EDTA in carbonate acidizing. 2. Compare results from coreflood experiments using EDTA, HAc, and HCl.	Neutron radiography to image wormhole structures in coreflood experiments. Use of EDTA as an alternative stimulation fluid.	EDTA forms wormholes in limestone at various pH values. EDTA eliminates the need for corrosion inhibitors and reducing agents. Wormhole structures depend on the Damkohler number and injection rate. Improved acid

								penetration with EDTA and HAc at low injection rates.
13	B. Bazin	SPE-66566-PA, 1998	From Matrix Acidizing to Acid Fracturing: A Laboratory Evaluation of Acid/Rock Interactions	Evaluates acid/rock interactions in matrix acidizing and acid fracturing processes. Compares acid injections at constant flow rates and pressure drops. Analyzes acid propagation rates and dissolution patterns using x-ray tomography.	Acid fracturing and matrix acidizing processes for carbonated reservoirs evaluated. Laboratory tests designed to improve well-stimulation operations.	1. Evaluate acid/rock interactions in matrix acidizing and acid fracturing processes. 2. Develop methodology for acid propagation rates and dissolution patterns.	Constant flow rate and pressure drop for acid injections comparison. Linear coreflood experiments with pressure monitoring and dissolution pattern analysis.	Acid/rock properties evaluation methodology presented with x-ray computed tomography analysis. Acid formulations performance compared based on propagation rates and dissolution patterns. Wormholes classified into branched and compact patterns for analysis.
14	M. Gong and A. M. El-Rabaa	SPE 52165, 1999	Quantitative Model of Wormholing Process in Carbonate Acidizing	The paper discusses a new model for carbonate matrix acidizing. It aims to predict wormhole length and estimate critical injection rate. The model involves acid transportation, acid-rock reaction, and acid diffusion.	Focuses on developing a model for carbonate acidizing in oil industry.	1. Develop a semi-analytical model for accurate wormhole length prediction. 2. Estimate the critical injection rate for carbonate matrix acidizing.	Developed a new semi-analytical model for wormhole length prediction. Validated the model through systematic experiments of linear core acid flood.	Developed a semi-analytical model to predict wormhole length accurately. Proposed a quantitative model for the wormholing process in carbonate acidizing. Achieved a significant increase in PI compared to other wells.
15	T. Huang, D. Zhu, and A. D. Hill	SPE 54723, 1999	Prediction of Wormhole Population Density in Carbonate	Predicts wormhole population density for efficient	Focus on wormhole population density in carbonate	1. Predict wormhole population density and required acid	Developed theory to predict dominant wormhole channels	Predicted wormhole population density using pressure field

			Matrix Acidizing	carbonate matrix acidizing treatment. Utilizes optimal acid injection flux and wormhole propagation rate theories. Example demonstrates acid volume prediction using wormhole population density estimation.	matrix acidizing treatment. Investigates wormhole initiation pressure gradient and acid injection flux optimization. Studies pressure gradients, wormhole propagation, and acid volume prediction	volume for matrix acidizing. 2. Investigate wormhole population density during matrix acidizing process. 3. Determine acid volume needed for wormhole propagation in carbonate reservoirs.	efficiently. Numerically simulated flow field around a wellbore to quantify phenomenon. Example provided to show application of wormhole population density model.	modeling. Determined acid volume needed for wormhole propagation based on models. Predicted 12 wormholes per foot in a typical carbonate reservoir.
16	C.N. Fredd, and M.J. Miller	SPE 58713, 2000	Validation of Carbonate Matrix Stimulation Models	Acid stimulation in carbonate reservoirs analyzed using three prevailing theories. Models predict wormhole formation conditions and simulate skin evolution. Laboratory and field validations identify gaps and guide further research.	Acidizing carbonate reservoirs forms wormholes for effective stimulation treatments. Wormhole formation theories and models are reviewed for optimal conditions.	1. Review existing theories and models of wormhole formation. 2. Identify conditions where models apply for acid stimulation treatments.	Surface area scaling method and wormhole density estimation method. Capillary tube approach and Damkohler number approach. Scaling injection rate based on wormholes and maintaining wormhole structure.	Models predict wormhole characteristics based on injection rate and fluid properties. Laboratory validation shows different models apply under specific dissolution conditions
17	M.A. Buijse	Onepetro, SPE, 2000	Understanding Wormholing Mechanisms Can Improve Acid Treatments in Carbonate Formations	Analyzes acid spending in wormholes through mathematical models and numerical solutions. Explores wormhole propagation rate, geometry, and fluid flow properties. Introduces dimensionless	Analyzes wormhole propagation rate, geometry, and acid spending in pores. Focuses on fluid flow properties and wormhole competition for pattern formation.	1. Study acid wormholing in carbonate formations and its growth properties. 2. Analyze acid spending in wormholes based on reaction and diffusion. 3. Investigate wormhole	Modeling wormholes as cylindrical pores and solving mass balance equations. Numerical solution through finite-difference scheme with exact results. Derivation of formulas based on Levich approximation for acid	Acid wormholing in carbonate formations studied, focusing on wormhole growth. Wormhole growth rate affected by injection rate, diffusion, and acid spending. Wormhole models based

				numbers to simplify mathematical equations in acid spending study. Discusses the impact of injection rate and diffusion rate on wormhole growth.		competition and fluid flow properties for scaling.	concentration. Introduction of dimensionless numbers like Peclet, Damkohler, and kinetic number.	on core flow tests should be used cautiously.
18	F. Golfier, B. Bazin, C. Zarcone, R. Lernormand, D. Lasseux and M. Quintard	SPE-68922-MS, 2001	Acidizing Carbonate Reservoirs: Numerical Modelling of Wormhole Propagation and Comparison to Experiments	New 2D simulator for carbonate reservoir acidizing validated on experiments. Model predicts wormhole propagation rate based on reservoir properties.	Paper focuses on acidizing carbonate reservoirs for enhanced productivity. Describes a new 2D numerical simulator validated on experimental data	1. Develop a numerical simulator for acidizing carbonate reservoirs. 2. Validate the simulator using experimental data on wormhole propagation.	2D numerical simulator with improved physics description validated on experiments. Coupled mechanisms of flow, dissolution, Darcy-Brinkman equation, and Stokes flow. Experimental validation using acidizing and salt water injection experiments. Mass transport equation with Darcy-Brinkman flow and reaction description. Dissolution figures, Pe-Da coordinates, breakthrough times, and dissolution regimes quantification.	Model reproduces dissolution figures observed experimentally and quantifies transitions. Correlation found with salt-under saturated salt solution system similar to limestone. Model offers efficient tool to understand physics and calculate breakthrough times. Wormhole breakthrough times and propagation rates compared qualitatively with experiments.
19	F. Golfier, C. Zarcone, B. Bazin, R. Lenormand, D. Lasseux and M.	Cambridge University Press, 2002	On the ability of a Darcy-scale model to capture wormhole	Study tests Darcy-scale model for wormhole formation during porous	Acid injection for rock permeability stimulation, focusing on wormhole	1. Develop Darcy-scale model for wormhole prediction in porous	Finite volume method used for numerical solution in two dimensions.	Experimental data on dissolution patterns in two-dimensional

	Quintard		formation during the dissolution of a porous medium	medium dissolution. Numerical approach validates model experiments reflecting acid injection in limestone.	formation mechanisms. Darcy-scale model to predict wormhole development in porous media.	media. 2. Validate model with acid injection experiments in limestone. 3. Study dissolution regimes and flow parameters' influence on wormhole development.		beds of salt grains. Validation of a Darcy-scale model for wormhole development during dissolution.
20	Mohan K. R. Panga and Murtaza Ziauddin	American Institute of Chemical Engineers, 2005	Two-Scale Continuum Model for Simulation of Wormholes in Carbonate Acidization	Two-scale model for wormhole formation in carbonate acidization simulations. Examined dispersion, heterogeneities, reaction kinetics, and mass transfer effects. Model predicts wormhole formation conditions and is validated with lab data.	Two-scale model studies wormhole formation in carbonate acidization process. Describes transport, reaction mechanisms, and influences on wormhole formation.	1. Develop a two-scale continuum model for porous medium dissolution. 2. Study wormhole formation during acid stimulation in carbonate cores.	Two-scale continuum model with structure-property relationships and evolving variables. Discretization on 2-D domain using control volume approach with upwind scheme	Model predicts wormhole formation based on dispersion, heterogeneities, and reaction kinetics. Qualitative agreement with laboratory data on carbonate cores and salt-packs.
21	T. J. L. de Oliveira, Petrobras, A. R. Melo, and J. A. A. Oliveira, ESSS, A. Z. I. Pereira	SPE-151823-MS, 2012	Numerical Simulation of the Acidizing Process and PVBT Extraction Methodology Including Porosity/Permeability and Mineralogy Heterogeneity	Paper on acidizing process and pore volumes to breakthrough (PVBT) extraction methodology in petroleum engineering. Focus on porosity, permeability, mineralogy heterogeneity in numerical simulations.	Paper on acidizing process and PVBT extraction methodology in petroleum engineering. Focus on matrix acidizing differences in sandstones and carbonates.	1. Develop methodology for acid treatment simulation in carbonate rocks. 2. Extract PVBT curves for different acid-rock formations numerically.	Numerical simulation in a commercial CFD package using finite volume method. Incorporation of heterogeneous porosity, permeability, and mineralogy in the modeling. Extraction of PVBT curves for different pair formation-acid using measured data. Simulation to	Good agreement with experimental data, capturing different wormhole patterns. Mineralogy significantly affects PVBT value in carbonate core plugs.

							capture preferential channels and dissolution patterns in wormholes.	
22	Ming Liu, Shicheng Zhang, Jianye Mou, Fujian Zhou	Springer, 2013	Wormhole Propagation Behavior Under Reservoir Condition in Carbonate Acidizing	Study on wormhole propagation in carbonate reservoirs under experimental conditions. Model coupling two-scale continuum model and reservoir flow model used.	Study on wormhole propagation in carbonate reservoirs under experimental conditions. Model couples two-scale continuum and reservoir flow models for simulations.	1. Study wormhole propagation behavior in carbonate reservoirs under experimental conditions. 2. Compare porosity generation methods and analyze wormhole propagation under reservoir conditions.	Two-scale continuum model for acid flow and porosity change. Model coupling for studying boundary conditions and wormhole propagation.	Normally distributed porosities simulate wormholing better. Compressed zone effect increases with decreased compressibility factor. Wormhole length has a maximal value. Distance between layers affects wormhole lengths and acid distributions.
23	O.O. Akanni and H.A. Nasr-El-Din	SPE-172575-MS, 2015	The Accuracy of Carbonate Matrix-Acidizing Models in Predicting Optimum Injection and Wormhole Propagation Rates	Paper on carbonate matrix-acidizing models for wormhole propagation rates.	Matrix stimulation enhances permeability near the wellbore in sandstone and carbonates. Acid injection creates wormholes to improve inflow performance in carbonate reservoirs. Various models predict wormhole formation and optimum injection rates.	1. Analyze carbonate matrix-acidizing models for optimum injection and wormhole rates. 2. Examine principles and assumptions behind the development of model equation.	Transition pore theory by Huang et al. (1997) for matrix acidizing. Two-scale model by Kalia and Balakotaiah (2007) for dissolution patterns. Network model approach for porous media dissolution by Hoefner and Fogler.	Models differ from experimental results by an order of magnitude. Two-scale models predict dissolution patterns for fluid-mineral systems. Semi-empirical correlation model improves by accounting for core size. Physically representative network model simulates transport and reaction effects.

24	T. T. Bekibayev, I. K. Beisembetov, B. K. Assilbekov, A. B. Zolotukhin, U. K. Zhapbasbayev and K. A. Turegeldieva	SPE-177372-MS, 2015	Study of the Impact of Reduced Permeability Due to Near-Wellbore Damage on the Optimal Parameters of the Matrix Acidizing in Carbonate Rocks	Study on reduced permeability impact on matrix acidizing in carbonate rocks. Investigates dissolution of carbonate rocks using a two-scale mathematical model. Focuses on the effectiveness of matrix acidizing in near-wellbore regions.	Investigates impact of reduced permeability on matrix acidizing in carbonate rocks. Focuses on near-wellbore damage and optimal acid breakthrough volume.	1. Analyze the impact of reduced permeability on matrix acidizing parameters. 2. Study the influence of near-wellbore damage on acid breakthrough volumes. 3. Determine optimal acid injection conditions for matrix acidizing in carbonate rocks.	Volumetric model for wormhole growth determination. Two-scale model for investigating dissolution of carbonate rocks.	Investigated dissolution modeling of damaged and undamaged rocks. Wormhole growth dynamics and skin factor calculations for matrix acidizing. Determined optimal acid injection volume and velocity for matrix acidizing.
25	Olatokunbo O. Akanni and Hisham A. Nasr-El-Din	SPE-181348-MS, 2016	Modeling of Wormhole Propagation During Matrix Acidizing of Carbonate Reservoirs by Organic Acids and Chelating Agents	Paper on wormhole propagation during matrix acidizing of carbonate reservoirs.	Explores the use of alternative acidizing fluid systems in high temperatures. Models wormhole propagation in calcite using a two-scale approach.	1. Model wormhole propagation in carbonate reservoirs using alternative acidizing fluids. 2. Investigate porosity heterogeneity impact on breakthrough during acid injection.	Two-scale model for wormhole propagation during carbonate acidizing. Modified reaction kinetics for acetic acid, EDTA, and DTPA.	Acid efficiency curves, optimum injection rate, and breakthrough time determined. Modified two-scale model used to study wormhole propagation.
26	Zhaoqi Fan , Xiaoli Li , Russell D. Ostermann , and Jie Jiang	Onepetro , URTeC: 2902519, 2018	An Efficient Method to Determine Wormhole Propagation During Matrix Acidizing	Paper content not reviewed by URTeC, author's responsibility. No warranty on accuracy, reliability, or timeliness of information. Information does not reflect URTeC's position. Reproduction, distribution, or storage without	Matrix acidizing stimulates carbonate reservoirs by creating high-permeability channels. Various dissolution patterns like wormholes are observed during acidizing treatments. Wormhole	Develop an efficient method to predict dominant wormhole trajectory. Investigate effects of acid properties and injection rate on wormhole propagation. Reduce computation	Proposed a new method for predicting dominant wormhole propagations. Utilized a combination of one-dimensional acid transport model and wormhole propagation preference. Validated the new method by comparing	One-dimensional model predicts wormhole propagation in acidizing process accurately. Wormhole growth rate relationship with injection rate is well-defined. Wormhole recognition in laboratory

				consent is prohibited.	propagation is challenging to predict due to complex flow conditions. Theoretical models represent dynamic wormhole propagation considering multiple mechanisms.	al expenses in determining wormhole propagation.	results with traditional correlations	involves uncertainties due to CT scanning. Wormhole radius variation during acidizing process is directly revealed. Heterogeneous domain analysis shows influence on wormhole propagation.
27	Robert C. Burton, Manabu Nozaki, Nola R. Zwarich, and Kenji Furui	Onepetro, SPE, 2018	Improved Understanding of Acid Wormholing in Carbonate Reservoirs through Laboratory Experiments and Field Measurements	Study on acid wormholing in carbonate reservoirs through experiments and field measurements. Analysis of experimental results and field data to enhance wormhole-penetration model. Conclusions drawn from laboratory data and field data analysis.	Focus on matrix-acid-stimulated wells in carbonate reservoirs. Discuss wormhole efficiency in acid-injection tests and field observations. Emphasize the impact of acid treatments on wellbore storage and fluid segregation.	1. To enhance understanding of acid wormholing in carbonate reservoirs. 2. Validate acid-wormholing model through laboratory tests and field measurements. 3. Optimize completion/stimulation design by analyzing acid wormholing in carbonate rock.	Linear-coreflooding tests with real-time CT scanning. Field measurements of fully completed well design.	Validity of acid wormholing model, wormhole structure, stability, shear band impact. Wormhole propagation understanding enhances stimulation design focusing on pump rate. Skin value of 4 achievable in carbonate reservoirs with high-rate designs. Laboratory tests show optimal injection rates for wormhole creation.
28	Jyoti Shanker Pandey, Negar Nazari, Kaj Thomsen, and Reza	SPE-189496-MS, 2018	A Novel Equipment-Friendly and Environment-Friendly Well Stimulation Fluid for	Matrix acidizing is a popular technique in Oil and gas industry to enhance the well productivity.	Focuses on a novel acid for carbonate reservoir stimulation. Compares the acid’s	1. Compare dissolution rates of Indiana limestone in different acidizing fluids.	Rotating disk instrument for dissolution rate data. Rheometer for rheological measurements.	FF-01 and 15 HCl have similar corrosion rates. Ultra-series FF-01 is a

	Barati		Carbonate Reservoirs: Better Wormholes and Lower Corrosion at Reservoir Conditions	For a successful acidizing job, dissolution behavior of formation rock with injected acid needs to be fully understood. At Reservoir conditions, dissolution rates of carbonate rocks in injected acid is one of the controls mechanisms of the wormhole formation and propagation.	efficiency, corrosion, and environmental impact. Acid's dissolution rate, viscosity, and impact on well tubing discussed.	2. Measure corrosive nature of acidizing fluids at reservoir conditions. 3. Determine the impact of acid additives on rock dissolution rate. 4. Assess corrosion rates of different acids on Cr-13 metal coupons.	ICP-OEM for measuring calcium ion concentration.	good alternative to 15 HCl. FF-01 shows minimum corrosion compared to other acids.
29	Jianye Mou, Xiaoshan Yu, and Lei Wang, Shicheng Zhang, Xinfang Ma, and Xinrun Lyu	SPE-191148-PA, 2019	Effect of Natural Fractures on Wormhole-Propagation Behavior	Natural fractures impact wormhole patterns in acidizing in carbonate rocks. Two-scale continuum wormhole model used to simulate wormhole propagation. Extensive numerical simulations conducted to study wormhole behavior.	Natural fractures impact wormhole patterns in carbonate matrix-acidizing. Acidizing creates wormholes to remove formation damage and stimulate reservoirs	1. Investigate wormhole behavior in naturally fractured carbonates. 2. Study the effect of natural fractures on wormhole propagation behavior. 3. Analyze wormholing behavior and natural-fracture parameters' impact.	Monte Carlo simulation method used for natural-fracture modeling. Two-scale continuum wormhole model established for wormhole propagation simulation. Extensive numerical simulations conducted to analyze wormhole behavior and parameters.	Natural fractures influence wormhole propagation behavior in acidizing. Wormhole patterns are simulated with and without natural fractures. Dominant wormholes are created based on acid-injection velocity. Natural fractures lead to thinner, sinuous wormholes compared to no fractures.
30	Haoran Cheng, Mateus Palharini Schwalbert, A. Daniel Hill and	Onepetro, SPE, 2020	A Fundamental Model for Wormhole Formation Including Multiphase	Simulation study on acid injection into water- and oil-saturated cores.	The paper focuses on simulating wormhole propagation in coreflooding experiments.	1. Develop a 3D two-phase model for wormhole propagation in rocks.	Finite volume method in OpenFOAM software for numerical solution.	Simulated wormhole propagation in two- or three-phase coreflooding experiments.

	Ding Zhu		Flow		It compares simulation results with experimental data on acid injection. Previous studies extended models to investigate acid injection effects.	2. Simulate wormhole propagation in carbonate rocks saturated with oil or gas.	Two-scale continuum model for simulating wormhole propagation.	Compared simulation results with experimental results on acid injection scenarios. Investigated two-phase flow effect using experimental data from matrix-acidizing coreflooding.
31	Wan Wei, Alireza Sanaei, Fabio Bordeaux Rego, and Kamy Sepehrnoori	SPE-212165-MS, 2023	High Performance Computing and Speedup Techniques in Geochemical Modeling of Matrix Acidizing	Geochemical modeling of matrix acidizing using speedup techniques for efficiency. Coupled model UTCOMP-IPhreeqc validated through analytical solution comparison.	Matrix acidizing enhances well productivity through acid injection below fracture pressure. Researchers focus on computational efficiency in geochemical modeling.	1. Evaluate computational efficiency of acidizing simulation using parallelized geochemical calculations. 2. Investigate speedup techniques in geochemical modeling of matrix acidizing.	Speedup methods based on relative geochemical component change. Pore-scale correlations to update Darcy-scale parameters during acidizing treatment.	Speedup techniques impact CPU time and geochemical calculations. Active grid numbers change with injection rates and speedup methods.