

Fracturing-Fluid pH and Conductivity Retention in Shale

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Abstract. Fluid pH can influence shale reactions, but it is not a standalone predictor of retained fracture conductivity. Mineral removal may create space while simultaneous weakening or particle release degrades a loaded flow path. This note proposes a comparison strategy that tracks inlet and outlet chemistry, exposure, mechanical response, and conductivity at matched stress. The resulting framework distinguishes an unloaded etching observation from demonstrated hydraulic benefit under closure and avoids treating equal pH as equal fluid chemistry.

Why pH alone does not predict conductivity

pH describes hydrogen-ion activity at a stated measurement condition. Two fluids at the same pH can differ in ionic composition, buffering, and reactive capacity. Their behavior in shale should therefore be compared using a documented formulation and exposure history. Acid-shale experiments examine property and pore-structure changes [1], while earlier conductivity work addresses water-based-fluid interactions more broadly [2].

The engineering endpoint is conductivity after the fluid has interacted with a loaded fracture. An increase in visible pore space or surface relief is not sufficient to establish this endpoint.

Rough-fracture flow depends on the connected aperture field [3], and closure mechanics changes that field as contacts carry load [4]. The net result must be measured rather than inferred from the sign of mineral dissolution alone.

Kakkar's study addresses stress and fluid sensitivity in preserved reservoir shale [5]. Wu and coauthors tested neutral, alkaline, and acidic brines in the 2017 investigation [6]. The related journal paper reports softening in all brines tested, with additional fines generation under acidic and alkaline conditions [7]. The alkaline tests included pH 11 and 12, and the acidic tests included pH below one. These are tested conditions, not recommended treatment targets.

This evidence supports evaluating more than swelling or clay content when comparing formulations. Independent water-damage work includes mineralogy and fines behavior [8]. Nanoindentation-based screening examines the mechanical response to additives [9]. Those complementary endpoints help distinguish a chemical change in the solid from a beneficial change in the loaded hydraulic path.

Table 1. Proposed pH-study observations and their interpretation.

Observation	Potential benefit	Competing explanation to examine
Mineral removal	Greater local opening	Loss of load-bearing support
Rougher etched surface	Persistent residual channels	Weaker asperities under closure
Lower effluent particle count	Reduced mobile solids	Particles retained inside fracture
Higher unloaded flow	More open pathways	Benefit disappears when reloaded

Defining the formulation and exposure

The recipe behind a pH label

Two fluids with the same measured pH can differ in the amount and identity of dissolved material used to prepare them. A proposed pH study should therefore retain the complete recipe, preparation order, fluid age, and measurement conditions. If the intention is to isolate a pH effect, identify which formulation components change when pH is adjusted. Otherwise, the experiment tests a package of simultaneous changes and the resulting conductivity difference should be described at that formulation level.

For example, a reference brine and an adjusted brine may differ in both pH and added-ion concentration. A treatment effect between them is real as an experimental contrast, but its assignment exclusively to pH requires a control addressing the added components. An additional matched formulation can help, provided it does not introduce a new uncontrolled difference. The purpose is not to make every chemistry variable identical, which may be impossible, but to define what the comparison can resolve.

The preserved-shale investigations tested specified neutral, alkaline, and acidic brines and related the observed behavior to fluid-shale interactions [6, 7]. Kakkar's broader stress and fluid study provides the related experimental context [5]. Those results motivate formulation-specific screening. They do not establish that a single pH label predicts conductivity independently of brine composition, sample mineralogy, exposure duration, or the stress at which the exposed surface is subsequently tested.

A fluid recipe should distinguish the pH measured before contact from the conditions observed during and after exposure. Record the measurement method, temperature, and sampling time. If the fluid changes after contacting the rock, the initial value alone does not describe the full treatment. This proposed record is particularly important when comparing a batch exposure with continuous flow, because the two designs impose different fluid-renewal histories.

Two treatments can begin at the same pH while differing in total chemical inventory, dissolved components, or the amount of fluid available per unit rock area. A pH-only label therefore omits

variables that may control the delivered exposure. The acid-fracturing and shale-fluid protocol literature motivates preserving the fluid recipe and material description alongside pH [1, 10]. The present framework does not assign reaction kinetics to any recipe.

A practical comparison should report fluid volume, exposed area, contact duration, flow or mixing condition, and whether the inlet composition was maintained. If pH is measured only at the end, describe it as an endpoint rather than a time history. Missing measurements should remain visible. The objective is to make two nominally similar treatments comparable before interpreting differences in conductivity as a pH effect.

Measurement conditions and delivered exposure

A reproducible record identifies where and when pH was measured: during preparation, immediately before injection, in a collected effluent sample, or under a separately controlled condition. Include the measurement temperature and any dilution or cooling before the reading. These details define the reported quantity. A room-temperature reading on a recovered sample should not be presented as a direct measurement inside a loaded, heated fracture unless the experiment actually measured that condition.

A proposed quality check repeats a reference solution measurement before and after a sample sequence and retains the instrument's documented calibration procedure. Report readings outside the instrument or procedure's validated range with the appropriate qualification. When the experiment uses a nominal formulation label such as acidic brine, keep the measured values as well. The label helps organize the design; it should not replace the observations needed to compare repeated preparations.

The inlet and outlet records also have different meanings. A difference between them can motivate investigation of interaction along the flow path, but it does not by itself locate the reaction or quantify its effect on conductivity. The sample may have changed during collection or handling. Link each reading to the corresponding fluid volume and collection interval, then interpret it alongside composition, solids, and hydraulic observations rather than using one outlet number as a complete exposure history.

A fluid treatment delivered for a fixed time may expose different specimens to different total volumes if their conductivities differ. A fixed-volume treatment can instead require different durations. Neither design is inherently wrong, but each answers a different question. A proposed study should select its primary exposure basis explicitly and retain both elapsed time and cumulative volume. Report the evolving flow rate so that the actual delivery can be reconstructed when pressure-controlled operation is used.

In a synthetic constant-rate example, 60 minutes at 0.1 mL per minute delivers 6 mL, while the same duration at 0.5 mL per minute delivers 30 mL. Equal duration does not mean equal delivered volume. Conversely, delivering 6 mL at those rates requires 60 and 12 minutes. These arithmetic differences should be visible before a conductivity ranking is interpreted as a chemical effect, especially when different formulations also change the achievable flow rate.

The treatment sequence matters as well. A brief aggressive exposure followed by reference brine is a different intervention from continuous exposure to the aggressive fluid. Name the stage at which conductivity is compared and record the amount of displacement fluid used before that measurement. Acid-exposure and coupled softening studies motivate attention to exposure conditions [1, 11]. They do not remove the need to distinguish contact duration, delivered fluid, and the state remaining after a flush.

Designing the hydraulic comparison

Controls and retained capacity

Use neighboring specimens with a recorded preservation history [12] and characterize initial mineralogy and mechanical response. A standardized shale-fluid protocol provides a useful screening precedent [10]. Include a reference brine, at least one candidate formulation, and a time-matched stress-only control. Record temperature, exposure duration, flow volume, and inlet and outlet pH using an explicit measurement method.

Equalize factors that can be held constant, and report those that cannot. Adjusting pH changes chemistry; the experiment should identify the added reagent rather than claim that only pH changed. Track effluent chemistry and solids where practical. Test conductivity before exposure, during exposure if feasible, after flushing, and after loading to the comparison stress. A final flush is itself a treatment and should be documented.

Define net retention $R_{\text{net}} = C_{\text{final}}/C_{\text{initial}}$ at the same stress, phase, and geometry convention. In a synthetic example, a fluid increases unloaded conductivity from 1.0 to 1.5 mD-ft but leaves only 0.4 mD-ft after the comparison stress is reapplied. The relevant final retention is 40%, despite the earlier 50% gain. This arithmetic illustrates the selected endpoint; it is not an experimental result.

A proposed screening design includes a reference brine and a limited set of pH-adjusted treatments, each tested on independent matched specimens. Keep the preparation method explicit, because changing pH can also change the ions introduced with the adjusting reagent. Where those compositional differences cannot be eliminated, document them and restrict the causal statement accordingly. A contrast between recipes is still useful even when it does not isolate pH alone.

Apply the same preservation, stress schedule, exposure duration, and hydraulic measurement protocol to every group. Include a loaded measurement after exposure, because an unloaded increase in opening may not persist under closure. The preserved-shale work explicitly motivates assessing fluid exposure together with stress [6, 7], while the thesis provides a propped/unpropped mechanical baseline [5].

Select primary endpoints before examining the results. A useful set is absolute loaded conductivity, retention relative to a stated baseline, and change relative to the reference brine. Mechanical response and effluent solids can help interpret those endpoints. If a treatment improves only one auxiliary metric, report that limited outcome rather than describing it as a conductivity-preserving fluid.

Flow response and geometric interpretation

A change in measured flow at fixed pressure drop can reflect a change in the fluid as well as a change in the fracture. The conductivity calculation should therefore use a viscosity appropriate to the measurement fluid and temperature, with its source or measurement documented. If conductivity is evaluated after replacing the treatment with a common reference fluid, explain the replacement criterion. A nominal switch at the pump does not establish that the entire measured flow path immediately contains the new fluid.

A proposed diagnostic compares the hydraulic response during treatment with the response after a defined reference-fluid stage at matched stress. An increase seen only during treatment should be distinguished from an increase retained afterward. This does not make the reference-fluid stage a neutral observation: it may itself change the specimen. A time-matched control subjected to the same switching sequence helps identify that contribution and preserves a clear interpretation of the final comparison.

The cubic-law baseline shows why small geometric changes can strongly affect idealized conductance [13], while rough-fracture theory limits the direct interpretation of an average opening [3]. Consequently, a measured flow increase cannot be converted into a uniform aperture increase without an explicit model. Present the measured conductivity first, then any model-derived aperture with its assumptions. This separates an observed hydraulic response from a geometric explanation that remains conditional on the chosen flow representation.

Testing whether a benefit persists

Reaction screening and load-bearing support

Coupled exposure experiments motivate attention to the duration and depth of altered material [11]. Mechanical-property tests can characterize the host-rock response [14], and conductivity procedures help control the hydraulic comparison [15]. For propped fractures, changes at the supporting wall should be considered together with embedment [16]. An additive that protects a local hardness measurement has not thereby passed the full conductivity test.

When comparing literature, retain the reported pH, fluid composition, mineralogy, stress, and contact time as a package. A ranking obtained for one carbonate-rich specimen need not transfer to a different clay-rich interval. The absence of a measured benefit is also informative: it may show that mineral removal and structural deterioration offset each other under the selected loading condition.

The hydraulic consequence of surface alteration depends on where material is removed and what remains to carry load. Greater separation measured without closure does not automatically imply greater loaded conductivity. A proposed test should therefore compare the treatment before and after reapplying the same stress, while documenting any irreversible changes introduced by the measurement sequence itself.

For a purely illustrative parallel-plate calculation, increasing aperture from 1.0 to 1.2 normalized units would increase conductivity by a factor of 1.2 cubed, or 1.728. If the altered surface subsequently closes to 0.8 units, the corresponding factor becomes 0.512 relative to the original opening. These values are consequences of an idealized geometric law, not predictions for an etched shale fracture. Roughness and contacts limit that simple conversion [3, 13].

The example explains why an apparent chemical benefit should be tested under mechanical loading. Pair hydraulic measurements with surface and mechanical observations if the goal is mechanism attribution. If increased opening and reduced support occur together, the net response must be measured or modeled with both effects. Assigning a favorable sign to mineral removal alone would omit the interaction that the experiment is intended to examine.

The subsequent stress challenge

A fluid-induced opening observed at low load may have limited relevance if it disappears under the intended stress range. A proposed persistence test measures the treated specimen through a defined loading and unloading sequence, with a matched untreated or reference-fluid group. Report both the immediate treatment response and the conductivity retained during the later stress challenge. The challenge should be specified before inspecting which treatment gives the largest initial increase.

Consider an illustrative treatment that raises low-stress conductivity from 0.10 to 0.30 mD-ft, followed by a high-stress value of 0.03 mD-ft. A reference specimen might start at 0.10 and retain 0.04 mD-ft under the same high stress. The treated specimen has the larger initial response but the lower challenged endpoint. These selected values show why a screening criterion based solely on immediate opening can rank treatments differently from one based on loaded conductivity.

Mechanical and surface observations can help explain such a reversal without being treated as substitutes for the hydraulic comparison. Examine whether the exposure changed supporting regions, generated particles, or altered contact geometry. The preserved-shale studies and water-damage work provide motivation for considering both stress and exposure [7, 8]. A new experiment should identify which accompanying observations were actually made and leave unsupported mechanism assignments open rather than infer them solely from the shape of a conductivity curve.

Interpreting the screening outcome

Null results, interactions, and uncertainty

A study may find no consistent ordering among its selected pH treatments. That result can be useful if the experimental contrast, specimen variability, and measurement resolution are clear. Report individual trajectories and the range of plausible treatment differences. Failure to detect a difference does not establish that all formulations are equivalent, especially when the uncertainty is large relative to the effect that would matter for the intended application.

A mixed result may instead reveal an interaction with specimen type or exposure sequence. If one formulation performs differently in two mineralogical groups, present the conditional outcomes rather than forcing a single overall winner. Distinguish a planned subgroup comparison from one noticed after examining the data. The latter can motivate a follow-up test, but it should not inherit the same evidential status as a contrast selected before the results were known.

The final recommendation should describe a tested operating region rather than a universal preferred pH. Specify the brine recipe, specimen population, stress path, exposure basis, and comparison endpoint. Then identify the boundary most in need of confirmation, such as longer exposure or a different mineralogical interval. This format makes the result usable for designing the next laboratory screen while preserving the difference between a controlled experimental finding and a field-scale fluid-selection claim.

The scope of a recommendation

A screening result should specify which fluid recipe performed better, over which stress interval, after what exposure, and for which specimen population. If a treatment's advantage disappears after reloading, report that dependence prominently. If the ranking changes between formations or mineralogical groups, retain the interaction rather than averaging it into a universal preferred pH.

Separate the laboratory finding from broader operational selection. The present framework evaluates fracture transmission under stated conditions; it does not assess every requirement of a field fluid system. A measured advantage should become an input to further evaluation, not a complete treatment recommendation. The interpretation can remain useful by identifying which mechanisms and conditions need confirmation.

A suitable next step is an independent repetition of the most promising and most uncertain contrasts, including a time-matched reference. Preserve failed or ambiguous tests in the record with reasons for exclusion from any summary. Natural scientific reporting includes results that limit a proposed explanation. This helps prevent a chemically attractive narrative from outrunning the hydraulic evidence on which the paper is based.

pH belongs in a formulation record and an experimental design, not in a universal conductivity ranking. Evaluate net flow capacity after realistic exposure and matched loading, with chemical and mechanical measurements used to explain the result. The proposed framework establishes what evidence would support a claimed benefit from changing pH. It does not recommend acid strength, alkaline treatment, or an operating recipe for any reservoir.

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Numbered references correspond to the citations in the text. Links lead to DOI records or the identified source record.

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