Current Trends in Fishbone Branch Well Drilling and Completion Designs and Operations

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Abstract: Fishbone branch wells provide a high-efficiency architecture for effective reservoir contact (ERC) while bypassing the capital intensity and logistical footprints of multi-lateral long-steps or large-scale hydraulic fracturing. This review evaluates the technological shift from niche stimulation tools toward integrated workflows encompassing reservoir screening, 3 Dimensions (3D) geo-steering, and autonomous branch creation. We contextualize fishbone systems within the Technology Advancement of Multilaterals (TAML) classification framework and analyze critical design sensitivities, including branch density, spatial orientation, and geo-mechanical stability. The study synthesizes advancements in drilling reliability, liner-based needle systems, and multi-physics performance evaluation. Finally, we identify strategic research gaps in branch interference modeling, the scalability of short-lateral operations, and cost-effective surveillance for complex multi-branch systems in oil, gas and geothermal applications.

Keywords: Fishbone branch wells; Multilaterals; TAML; Effective reservoir contact (ERC)

1. Introduction

Multilateral wells (MLWs) create two or more wellbores connected to a single mainbore, enabling larger reservoir contact with fewer surface slots and, in many settings, smaller environmental footprints than multiple separate wells. Standardized definitions such as the Technology Advancement of Multilaterals (TAML) classification are widely used to describe junction complexity, isolation, and re-entry requirements, and remain a common reference for design communication and risk allocation [1].

Fishbone branch wells can be viewed as a specialized subset of MLW architectures. Instead of small number of long laterals, fishbone wells commonly deploy many short laterals that radiate from the main drain or from liner subassemblies. The objective is to increase near-wellbore connectivity, intersect natural fractures, and access thin or compartmentalized pay intervals where a single long lateral may suffer from limited drainage or rapid coning/breakthrough [2].

Recent open-access literature and public case materials emphasize three trends. First, liner-deployed systems have matured, enabling multiple laterals to be created quickly once the reservoir liner is in place, with laterals driven by fluid circulation and downhole turbines or jetting mechanisms [3]. Second, there is growing use of numerical/optimization methods to select branch patterns and to co-design inflow-control strategies in multilateral systems—concepts that translate naturally to fishbone wells where inflow imbalance can negate added contact area [4-5]. Third, operators increasingly report fishbone pilots in tight or layered reservoirs where stimulation time and logistics dominate economics, making lower-footprint stimulation attractive [6-8].

This review aims to (1) map fishbone wells to the broader multilateral classification and completion options; (2) consolidate recent findings on design parameters, drilling execution, and completion strategies; (3) summarize performance evaluation and verification methods; and (4) identify practical gaps and research opportunities for reliable, repeatable deployment. Figure 1 provides a visual definition of the fishbone geometry used throughout this paper [9-11].

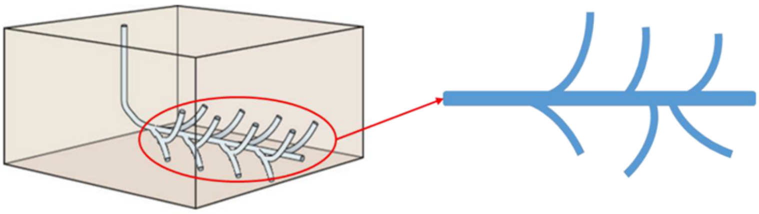

Figure 1: Fishbone drilling concept in which multiple micro-branches are created from a main lateral to enlarge well–reservoir contact and stimulated reservoir volume.

2. Fishbone Branch-Well Concepts and Design

From a drilling and completion viewpoint, fishbone wells occupy an intermediate space between classic multilateral wells with a few long laterals and near-wellbore stimulation techniques such as perforating and acidizing. The defining feature is the multiplicity of short laterals created from a primary drain, typically intended to enhance connectivity and reduce flow convergence near the wellbore. These laterals may be drilled or jetted during completion, and are often not designed for future intervention, which influences the junction requirements and the completion philosophy [11-12].

A useful starting distinction is therefore between (a) intervention-capable branches that require a junction enabling re-entry and, ideally, hydraulic isolation; and (b) micro-laterals created for connectivity where re-entry is not expected. Many fishbone deployments fall into the second category and do not require the same level of mechanical and pressure integrity as TAML 5 junction systems. However, hybrid architectures exist—for example, a high-integrity junction connecting two main laterals combined with micro-lateral stimulation along one or more drains.

2.1 Terminology: Branches, Laterals, and Junction Levels

The TAML system (Levels 1–6) classifies junctions by increasing mechanical complexity, re-entry capability, and hydraulic isolation. Contemporary summaries such as the Oilfield Review 'Defining' series remain widely used for practical definitions and for communicating design expectations across drilling, completion, and reservoir teams [13]. Level 5 junctions typically provide high strength and pressure integrity with full re-entry capability, and are common in offshore developments where long well life and intervention access justify higher completion cost [14-16].

By contrast, fishbone micro-laterals created by liner-deployed drilling/jetting subs are typically evaluated through (i) deployment reliability, (ii) wellbore stability during lateral creation, (iii) cuttings/return management, and (iv) the resulting inflow distribution along the main drain[17-19]. Because intervention is not expected, the design focus shifts from junction hardware to repeatability and predictability of the created lateral network.

2.2 Why Fishbone Wells are Used

Recent literature and public case materials cluster the motivations into three categories:

Productivity: increase near-wellbore contact area, intersect natural fractures, and reduce effective skin in low-permeability or layered reservoirs [5-7].

Conformance and sweep: create distributed inflow points that mitigate heel-to-toe and reduce early water/gas breakthrough when coupled with flow-control devices [19].

Cost and operational constraints: reduce the number of surface wells and potentially replace or reduce large-volume hydraulic fracturing where logistics, footprint, or induced-seismicity concerns dominate [8-10].

In practice, fishbone wells are most attractive when the incremental benefit of each additional surface well is low (e.g., limited slots or pad constraints), while the marginal cost of adding micro-laterals along a single well is modest. The business case should therefore be framed in terms of incremental net present value per deployed sub or per branch cluster, not only in terms of initial rate. Table 1 summarizes a qualitative analysis comparison between multiple well families and typical fish bone characteristics.

Table 1. Comparison of multilateral well families and typical fishbone features (qualitative).

Attribute	Conventional MLW (few long laterals)	Fishbone branch well (many short laterals)
Primary objective	Maximize reservoir contact with a limited number of long drains	Enhance near-wellbore connectivity and distributed inflow
Junction requirement	Often high-integrity junctions with re-entry (TAML 3–6)	Frequently liner-deployed micro-laterals; re-entry usually not required
Typical lateral length	Hundreds to thousands of meters	Meters to tens of meters per needle/micro-lateral
Operational emphasis	Junction construction, isolation, intervention access	Deployment reliability, transport/returns management, pattern spacing
Completion focus	Selective isolation/ICDs/ICVs at laterals and junction	Integration with liner, distributed stimulation, optional inflow control

2.3 Integrated Design Workflow for Fishbone Branch Wells

A recurring theme in the recent literature is the need for an integrated workflow that connects reservoir screening, branch-pattern selection, drilling feasibility, completion design, and economic evaluation. Fishbone wells can fail to add value if branches are placed in low-quality rock, if branch interference leads to rapidly diminishing returns, or if completion inflow becomes highly unbalanced. Therefore, most workflows start with candidate screening and end with surveillance and post-job learning to update design heuristics [14].

2.4 Reservoir and Candidate Screening

Fishbone wells are often considered in thin pay where vertical placement tolerance is small, in layered or compartmentalized systems where short laterals can link isolated layers, and in naturally fractured reservoirs where micro-laterals can intersect existing fracture networks [5-7]. Screening should include rock mechanical limits for micro-lateral stability, depletion and pressure windows (especially if branches are drilled rather than jetted), and the expected conformance risks (gas-cap or water coning, thief zones, or high-permeability streaks).

Fields that suffer early breakthrough may benefit more from combining connectivity with conformance controls than from connectivity alone. Optimization and evaluation studies on multilateral intelligent completions demonstrate that valve/device choices and control strategies can materially affect water production and NPV under heterogeneity [3-4]. Although these studies are not fishbone-specific, they highlight a general principle: more flow paths increase degrees of freedom, so without control they can increase imbalance.

2.5 Branch-Pattern Variables and Constraints

Typical fishbone pattern variables include branch number (N), branch length (Lb), spacing along the mainbore (S), azimuth distribution (Δθ), and inclination (α). The feasible design space is constrained by sub count, rig time (or completion time), transport and returns limits, and the risk appetite for nonproductive time. Reviews emphasize that pattern selection should be tied to anisotropy and expected drainage radius, because excessive branch density can lead to strong interference with minimal incremental recovery [5].

Practically, engineers often define a repeating "cluster" pattern (e.g., three needles per sub at fixed azimuths) and then optimize the number and placement of clusters along the well. This is analogous to stage design in unconventional fracturing, but the physics differs because micro-laterals create discrete conduits rather than induced fracture networks. The design should therefore explicitly state the assumed mechanism of benefit: fracture interception, layered connectivity, or distributed inflow. As conceptualized in Figure 2, screening models often approximate each branch's effective drainage/stimulated region and then check for overlap to avoid excessive interference[11].

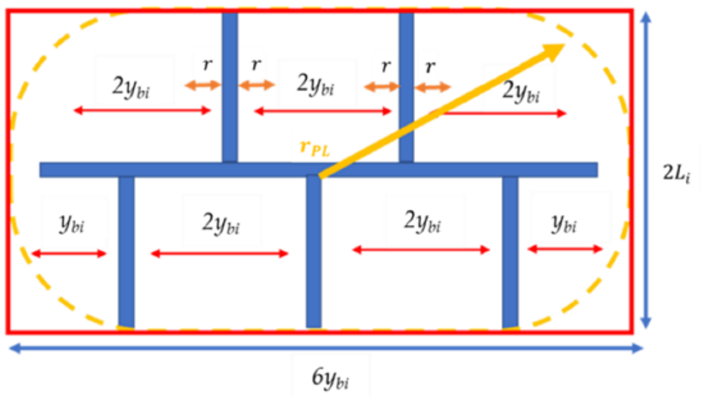

Figure 2: Conceptual "stimulated volume" representation for a fishbone layout, distinguishing inner and outer regions and indicating characteristic drainage/stimulation dimensions used in early design calculations.

2.6 A Simple Productivity Framing for Early Screening

For quick screening, a fishbone well can be approximated as a primary horizontal well with an effective near-wellbore conductivity increased by branches. One qualitative representation is to define an "effective contact factor" $F_c = 1 + \sum_i wi(L_b, i, ki, \alpha i)$, where wi reflects the relative productivity contribution of branch i compared with the main drain, and depends on local permeability/anisotropy and branch orientation. Although Fc is not directly measurable, it encourages engineers to compare designs based on incremental contribution per branch and to consider interference (wi decreasing as branch spacing becomes small relative to drainage radius). Reviews and modeling papers highlight that explicit simulation is often needed to quantify interference under multiphase flow.

Recent open-access parametric studies provide useful qualitative guidance for screening and for setting initial design bounds. Figure 3 summarizes the influence of branch count on cumulative production, Figure 4 illustrates the trend with branch length, Figure 5 shows the sensitivity to permeability anisotropy (a proxy for vertical connectivity), and Figure 6 highlights how inter-branch spacing can shift the degree of branch interference. These plots are used here as representative trends rather than universal correlations [11].

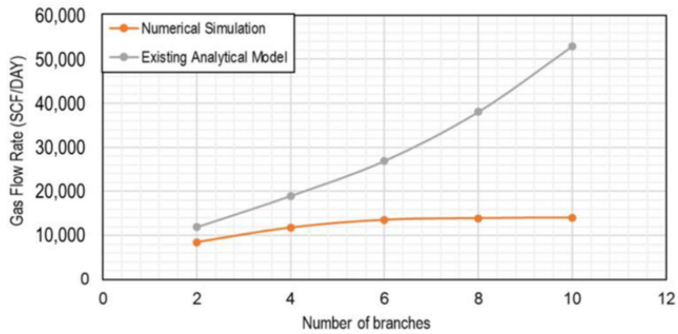

Figure 3: Sensitivity of cumulative gas production to the number of branches (comparison between numerical simulation and an analytical model).

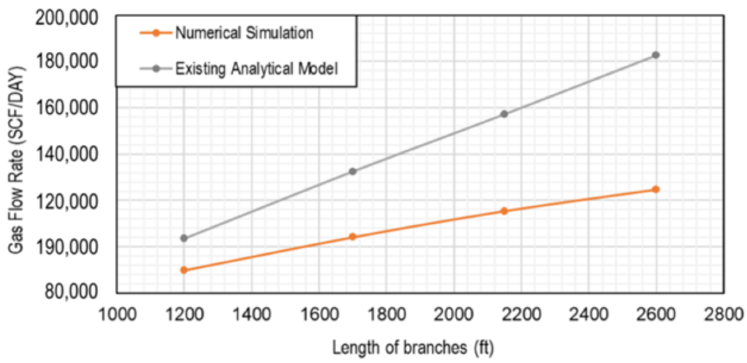

Figure 4: Sensitivity of cumulative gas production to branch length (numerical simulation vs. analytical model).

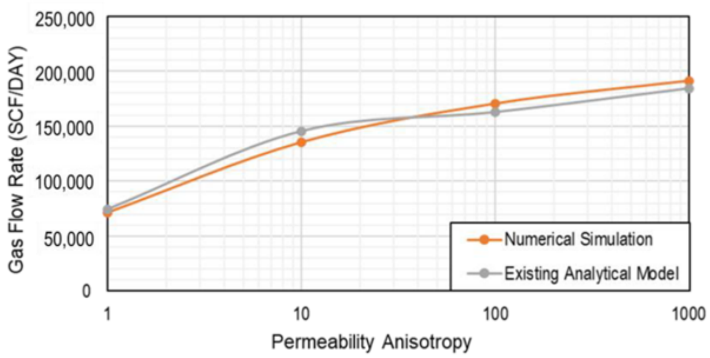

Figure 5: Effect of permeability anisotropy on fishbone-well productivity, illustrating the role of vertical communication in effective drainage.

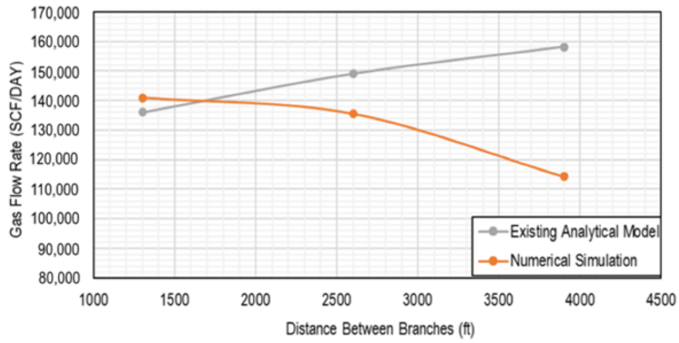

Figure 6: Effect of distance between adjacent branches on cumulative production, illustrating the trade- off between drainage extension and branch interference.

2.7 Economics and Decision Criteria

Because fishbone designs may add cost (subs, deployment time, specialty tools) but also reduce the number of drilled wells, the economic decision is rarely a simple comparison of initial rates. A practical criterion is to compare (i) incremental recovery per dollar and per day of rig/completion time, and (ii) the risk-adjusted probability that the incremental recovery will be realized. Public case materials often emphasize "fast deployment" as a key advantage, which directly reduces the time-at-risk for operations and can improve cost predictability [14].

3. Drilling, Completion, and Performance Evaluation

Fishbone wells combine conventional directional drilling for the mainbore with specialized methods to create multiple short laterals. Two broad approaches are common: (i) liner-deployed drilling/jetting subs that create micro-laterals during completion, and (ii) drilling-based sidetracks (open-hole or cased-hole exits) that create short branches requiring navigation and potentially re-entry capability [15-17].

3.1 Mainbore Placement and Geosteering

Mainbore placement is critical because fishbone branches typically start from within the pay zone and have limited vertical tolerance. Field experience shows that geo-steering is used not only to stay in-zone but also to support directional control during multi-branch operations. A published SPE case from the Russkoye field demonstrates that geo-steering workflows can be extended to multilateral fishbone wells to support both geological targets and directional drilling decisions during branch creation [16].

In thin reservoirs, the mainbore acts as the reference trajectory for all branches. Therefore, anti-collision and spacing analysis should treat each planned branch cluster as a swept volume, not just as a single line, especially where multi-well pads create dense well patterns. This becomes increasingly important as branch count increases and as the tolerance for dogleg severity and tortuosity tightens in long horizontals.

3.2 Liner-Deployed Micro-Lateral Creation

Liner-deployed systems describe a workflow in which the reservoir liner is run as normal, but includes multiple subs spaced at designed intervals. According to public technical descriptions, each sub can deploy several small-diameter laterals powered by fluid circulation and downhole turbines, with drilling completed in a short operational time [6]. In carbonate settings, jetting systems combined with acid can create laterals while simultaneously stimulating the near-wellbore region [14].

The main engineering controls are (i) deployment reliability (probability that each needle deploys and reaches expected penetration), (ii) trajectory uncertainty (azimuth and inclination control), and (iii) cuttings/returns behavior. These controls should be part of the design acceptance criteria; for example, a deployment KPI may be "≥X% of needles deployed to ≥Y m penetration", while a performance KPI may be measurable incremental inflow from Z targeted intervals.

3.3 Drilling-based Side Tracks and Re-entry Reliability

When branches are drilled using conventional drilling assemblies (including whip stocks, deflection tools, or coiled-tubing drilling systems), re-entry and "forward drilling" reliability becomes a key risk. Experimental and numerical work has analyzed how bottom-hole assembly (BHA) geometry, wellbore curvature, and junction shape influence the ability to re-enter the main hole during forward drilling of fishbone wells, highlighting sensitivities to curvature and to tool/bit size ratios [15].

These findings motivate careful planning of junction geometry, dogleg limits, and operational practices such as maintaining gauge hole and managing ledges. In addition, if multiple branches are drilled from a long horizontal mainbore, the cumulative effect on torque and drag can be substantial, affecting the ability to reach planned kickoff points and increasing stuck-pipe risk.

3.4 Wellbore Stability, Drilling Fluid, and Transport

Many fishbone candidates are thin or depleted reservoirs with narrow mud-weight windows. Stability concerns can be amplified by repeated branch creation, which introduces local stress concentrations and potential washouts. In addition, transport is challenging because cuttings and debris from multiple short laterals must be carried through a long mainbore. Therefore, operational design should include conservative transport criteria, monitoring of equivalent circulating density, and contingency plans if returns degrade.

Although detailed datasets are rarely public, general multilateral experience highlights the importance of fluid selection, ROP management, and cement/casing-exit quality for junction integrity in intervention-capable systems [18-19]. For fishbone micro-laterals, the key is repeatable deployment with minimal additional risk to the base completion. Table 2 displays the typical drilling and completion elements for fishbone/branch well construction.

Table 2: Typical Drilling and Completion Elements for Fishbone/Branch-well Construction.

Element	Typical role in fishbone wells	Notes
Geosteering (LWD/real-time models)	Maintain mainbore in thin pay; support branch kickoff decisions	Demonstrated for fishbone MLWs in SPE case studies[16]
Whipstock/casing exit systems	Create cased-hole exits when intervention-capable branches are required	Common in higher-TAML systems[17]
Liner-deployed drilling/jetting subs	Create multiple small-diameter laterals during completion	Public descriptions by Fishbones AS; field presentations[13]
Flow control devices (ICD/AICD/ICV)	Balance inflow and delay breakthrough	Optimization studies show strong sensitivity under heterogeneity[3-4]
PLT / distributed sensing	Verify branch contribution and detect imbalance	Used in public case presentations for fishbone wells[14]

3.5 Needle Deployment, Penetration, and Connectivity

Needle systems are customized by formation type: in carbonates, acid-assisted jetting creates conduits and stimulates the near-wellbore, whereas in tighter sandstones, drilling may supplement jetting to ensure sufficient penetration [9-13]. The key engineering challenge lies not only in individual needle reach, but also in whether the induced network effectively intersects target features (fractures, layers, or faults) and sustains conductivity over time.

Case studies highlight that success frequently depends on precise interval selection and clustering within specific layers. For instance, an industry-reported fishbone jetting system across multiple layers yielded production significantly above expectations, as verified by PLT, leading to its adoption as a base-case design in further development [14]. While such reports do not provide full subsurface details, they underscore the importance of verification and of translating early pilots into repeatable design rules.

3.6 Integration with Inflow Control and Intelligent Completions

As the number of branches increases, inflow tends to become more heterogeneous, particularly in layered formations. This effect can be mitigated by integrating passive or autonomous inflow control devices (AICDs) along the mainbore with the fishbone lateral system, reducing heel-to-toe imbalance and preventing a few high-permeability zones from dominating production. Recent multilateral optimization studies demonstrate that strategic combinations of flow-control devices and operational policies can significantly impact net present value (NPV) and water cut, offering a structured approach to co-design completions and production strategies [3-4].

In high-cost environments where hydraulic isolation and future intervention are required, high-integrity junction systems (e.g., TAML 5) can be combined with intelligent completions to control each branch independently [17-19]. Although such systems can exceed typical fishbone cost targets, they illustrate how branch architectures and flow-control can be co-optimized when lifecycle value (not only initial rate) is the key driver.

3.7 Operational QA/QC for Stimulation Outcomes

Because fishbone laterals are created during completion or shortly thereafter, quality assurance requires a mix of indirect indicators (pumping signatures, pressure response, returns) and direct indicators (PLT or production response). A practical QA/QC plan should define (i) deployment success metrics (number of needles deployed, penetration achieved), (ii) well integrity checks (pressure tests, annular monitoring), and (iii) a verification program to estimate incremental contribution over an agreed time window.

3.8 Production Evaluation and Surveillance

Quantifying fishbone value requires separating the incremental benefit of branches from confounding effects such as changing choke strategy, pressure support, or background stimulation. Recent literature uses a combination of (i) production data analysis and diagnostic plots, (ii) production logging or distributed sensing, and (iii) reservoir simulation with explicit representation of branch geometry or equivalent well indices [20-23].

3.9 Modeling Approaches: Explicit vs. Equivalent Geometry

Explicit modeling treats each branch as an individual well segment with unique trajectory and completion properties. While computationally demanding for extensive micro-lateral networks, this approach has become increasingly viable with modern simulation capabilities. Alternatively, equivalent methods aggregate branches into an effective well index or skin factor calibrated to limited data. However, reviews caution that such simplified methods may overlook nonlinear effects arising from branch interference and multiphase flow, which are not fully represented by scaling factors alone [5].

A pragmatic modeling strategy is to use a tiered approach: (1) analytical screening to rule out clearly non-economic designs, (2) a small number of detailed explicit simulations to calibrate reduced-order models, and (3) optimization loops that use the reduced-order models to explore design alternatives. Similar tiered strategies are common in intelligent completion design studies [3-4].

3.10 Verification and Surveillance

Production logging (PLT) provides direct verification of interval contribution post-deployment, with public fishbone cases confirming significant production gains [14]. In complex multilaterals, permanent monitoring and control systems offer continuous diagnostics at increased cost and reliability risk [19]. Thus, a "minimum viable surveillance" approach is recommended—collecting sufficient data to calibrate design models without over-instrumenting wells.

From a reservoir management perspective, surveillance should also monitor risks such as premature water breakthrough through newly connected high-permeability features. Where feasible, data should be interpreted within a consistent modeling framework to enable systematic design improvement rather than anecdotal adjustments.

3.11 Field Applications and Lessons Learned

Public field evidence on fishbone wells is most often disseminated via technology notes, case summaries, and industry presentations rather than fully peer-reviewed datasets. Even so, several consistent themes recur: (i) candidate selection is decisive—impact is greatest when laterals deliberately intersect discrete high-quality features (e.g., fracture corridors, thin oil rims, bypassed layers) rather than being uniformly distributed in homogeneous rock[14]; (ii) operational repeatability underpins economics, making rapid, predictable deployment—particularly with liner-deployed systems—a key advantage[6]; (iii) early diagnostics accelerate learning, with PLT or equivalent measurements commonly used to verify branch contributions and optimize subsequent designs[14]; and (iv) connectivity must be balanced by conformance, as added flow paths can exacerbate inflow imbalance unless managed through completion design and operating strategy [19].

Beyond fishbone-specific reports, multilateral case studies with high-integrity junctions offer transferable insights into lifecycle value and risk control. For instance, an SLB offshore case study describes an extended-reach intelligent TAML 5 well targeting a thin oil rim between a gas cap and water; the multilateral configuration enabled selective control and improved production sustainability relative to earlier designs [19]. While not a classic fishbone layout, it illustrates the benefit of coupling branch architectures with flow control to mitigate breakthrough risks.

Cross-industry literature (e.g., geothermal) provides additional context: reviews and workshop papers emphasize multilateral architectures to increase heat-exchange area and access multilayer reservoirs, reinforcing the broader principle that branching trades geometric complexity for improved subsurface contact [21-22].

3.12 Branch Interference and Uncertainty Quantification

A persistent technical gap is quantifying interference between multiple micro-laterals under multiphase flow and stress-sensitive permeability. Reviews note that analytical models may under-predict interference and that fully coupled simulation can be expensive for optimization [5]. Key research directions include reduced-order models that preserve interference physics, better uncertainty quantification for branch placement, and calibration strategies that use limited surveillance data efficiently.

3.13 Operational Limits and Scale-up

Scaling from a few branches to dozens increases cumulative risk: tool reliability, transport/returns management, fatigue in repeated operations, and trajectory uncertainty. Research on forward drilling and main-hole re-entry indicates that BHA geometry and junction shape affect re-entry success and therefore operational efficiency in multi-branch drilling [15]. Future work can integrate such mechanics into real-time decision support and into "design for drillability" rules for branch clusters.

3.14 Completion–conformance Coupling

Fishbone wells can increase contact area but may also connect to high-permeability streaks that dominate inflow. Optimization studies on multilateral completions demonstrate that joint design of flow-control devices and control strategy can materially change NPV and water production [3-4]. For fishbone wells, a key opportunity is to develop low-cost conformance solutions that are robust to uncertainty—e.g., distributed passive devices or simplified autonomous devices—supported by field-scale validation.

3.15 Diagnostics at Acceptable Cost

Because many fishbone deployments target cost-sensitive onshore wells, full intelligent completions may be uneconomic. A practical opportunity is to develop lower-cost diagnostic packages for multi-branch wells, combining short-duration PLT campaigns, selective fiber-optic deployments, and model-based inference. Public case narratives highlight the value of PLT confirmation, but detailed uncertainty reporting is rare [14]. Table 3 shows the common technical risks in fishbone branch wells and typical mitigation measures.

Table 3: Common Technical Risks in Fishbone Branch Wells and Typical Mitigation Measures.

Risk Area	Typical Manifestation	Mitigation Examples
Branch interference	Diminishing incremental recovery with increasing branch density	Tie branch spacing to expected drainage radius; calibrate with explicit simulation and surveillance [23-25]
Deployment reliability	Incomplete needle deployment or insufficient penetration	Define deployment KPIs; use pumping/pressure signatures; perform post-job verification [14]
Inflow imbalance	A few branches dominate; early water/gas breakthrough	Use distributed inflow control; optimize device placement and strategy [19]
Transport/returns	Poor hole cleaning; increased NPT	Conservative hydraulics design; monitor returns; contingency plans for cleanout.
Model uncertainty	Mismatch between design and realized geology/fractures	Use probabilistic screening; integrate geo-steering and post-job learning loops [16]

4. Conclusion

Fishbone branch wells have evolved into a credible engineering option for improving reservoir connectivity, especially in thin, layered, or naturally fractured reservoirs where conventional single laterals or large-scale hydraulic fracturing face cost or operational constraints. Recent publications emphasize integrated workflows that link reservoir screening, branch-pattern selection, drilling feasibility, completion flow control, and verification.

Key enablers include (i) standardized multilateral terminology (TAML) to specify junction requirements; (ii) liner-deployed drilling/jetting that streamlines multi–micro-lateral creation; and (iii) improved modeling and optimization of completion flow controls applicable to branch-well systems. Remaining challenges include (i) field-scale prediction of branch interference; (ii) repeatable short-lateral deployment within tight operational windows; (iii) cost-effective conformance integration; and (iv) practical surveillance programs that sustain cross-well learning.

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