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Well Integrity and Reservoir Behavior under Sudden Field Shutdowns During Armed Conflicts: A Comprehensive Technical Review

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Abstract

In the oil and gas industry, the sudden and unplanned cessation of operations resulting from armed conflicts or pandemics typically poses complex and multifaceted technical challenges to both well integrity and reservoir behavior. Minimal or no opportunity for proper pre-shutdown preservation procedures in unplanned shutdowns, unlike planned shutdowns that follow established operational protocols. The mechanisms and consequences of well integrity degradation and reservoir performance alteration under such conditions are synthesized in this review. Key topics examined include well barrier system failures such as cement sheath degradation, casing corrosion, sustained casing pressure (SCP) buildup, and wellhead seal deterioration. Reservoir-related phenomena including pressure redistribution, interzonal crossflow, asphaltene and paraffin wax precipitation, inorganic scale deposition, and clay swelling are also analyzed. Additional challenges specific to conflict zones, such as loss of monitoring capacity, infrastructure damage, and absence of operational personnel, are considered. The review further addresses the technical challenges and strategic approaches required for safe field re-commissioning and restart following conflict resolution. The analysis focuses on case studies from Iraq, Libya, and the broader Middle East and North Africa (MENA) area, where recurrent conflict-driven shutdowns have recorded the breadth of subterranean and surface repercussions. The findings underscore that the longer the unsupervised shutdown duration, the more severe and potentially permanent the well integrity and reservoir damage become, and that a structured, risk-based well-recommitting strategy is crucial for safe and efficient field restart.

Keywords: Well integrity, armed conflict shutdowns, reservoir behavior, sustained casing pressure, field re-commissioning, unplanned well shutdowns

INTRODUCTION

The NORSOK Standard D-010 defines well integrity as "the application of technical, operational, and organizational solutions to reduce the risk of uncontrolled release of formation fluids throughout a well's life cycle" [1, 2]. The oil and gas industry has long understood that well integrity is essential for safe and profitable petroleum production. Several barrier components, such as production casings, tubing strings, cement sheaths, packers, and wellhead components, preserve the integrity of the wellbore system. These barriers are susceptible to ongoing degradation mechanisms under typical operating conditions, including corrosion, fatigue, heat cycling, and chemical attack. These mechanisms are controlled by planned inspection, maintenance, and monitoring programs [3].

However, all preventive and corrective maintenance operations are halted concurrently when oil and gas fields are suddenly shut down owing to armed conflict.

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In contrast to planned or economically motivated shutdowns, a unique convergence of threats to well integrity and reservoir performance is created by the lack of personnel, loss of monitoring data, interruption of utility systems (power, water injection, chemical injection), and the possibility of physical damage to surface and subsurface infrastructure [4].

Examples from conflict areas in the past highlight the seriousness and widespread nature of this issue. Following the Iraqi invasion of Kuwait in August 1990, the country's oil production—roughly 1.5 million barrels per day (MMbbl/d)—was virtually shut down, hundreds of wellheads were purposefully destroyed, and years of rigorous cleanup were required to restore output [5]. Libya's crude oil production has fluctuated significantly owing to the country's ongoing civil conflict since 2011; in late 2021 alone, forced shutdowns affected an estimated 0.4 MMbbl/d, and infrastructure damage has limited exploration and new development for more than ten years [6]. The most recent instance of a global supply disruption of at least 10 MMbbl/d throughout the Gulf region occurred in 2026, when the escalation of the Middle East conflict caused Iraq's largest oil field, Rumaila, to completely halt production after storage tanks reached capacity owing to blocked export routes [7].

However, there is still a lack of coherence in the scientific and engineering literature on shutdowns caused by conflicts. Most technical articles focus on either the physical damage to surface infrastructure or the economics of supply disruption, with relatively little systematic attention paid to the subsurface technical effects, such as downhole well integrity degradation and reservoir behavior alteration. By thoroughly synthesizing scientific literature on both topics, this study fills this knowledge gap and provides field managers and petroleum engineers with a structured understanding of the dangers, mechanisms, and mitigation techniques related to conflict-driven field shutdowns.

Scope and Objectives

The following particular technical queries are addressed in this review:

- What are the main ways in which unexpected, unsupervised shutdowns undermine the integrity of the well barrier?
- How do fluid distribution, rock-fluid interaction, and reservoir pressure change over an extended period of production suspension?
- Which particular exacerbating factors, such as lack of monitoring, damage to infrastructure, and loss of injection support, are brought about by the conflict context?
- What technical techniques and operational procedures can reduce damage during a shutdown and enable a safe field restart?

WELL INTEGRITY FUNDAMENTALS AND FAILURE MECHANISMS

Definition and Barrier Philosophy

The foundation of well integrity, as outlined in ISO 16530-1 and NORSOK Standard D-010 (Rev. 4, 2013), is the concept of independent and verifiable barriers. To stop the uncontrollable release of formation fluids into the environment, a well must have at least two separate pressure-containing barriers. Both primary (production casing, cement sheath, and tubing) and secondary (wellhead components, safety valves, and packers) components are included in these barriers [1, 8].

Since its introduction into the petroleum industry in 1903, the cement sheath has been considered the main component of well barriers. During well construction, it is injected into the annular space between the steel casing and wellbore wall to perform three crucial tasks: (1) preserve zonal isolation between formation intervals; (2) shield the casing from external corrosive formation fluids; and (3) offer mechanical support to prevent casing deformation under formation loading [9, 10].

A Well Integrity Management System (WIMS) that maintains barrier status, monitors key performance indicators (KPIs), and plans inspection and maintenance tasks is necessary for well integrity management in developed fields. The accumulation of unsolved integrity issues that can quickly worsen when routine maintenance is interrupted is a serious concern in mature fields, which make-up the majority of fields impacted by political strife [11].

Cement Sheath Failure During Prolonged Shutdown

The cement sheath is particularly susceptible to deterioration in the event of an extended, unattended shutdown. Fatigue in casing connections and debonding or cracking in cement sheaths can result from cyclic loads caused by temperature and pressure changes during regular production/injection cycles, start-ups, and shutdowns [3]. Several failure mechanisms are triggered when a shutdown occurs abruptly and lasts for months or years, as in conflict situations.

Thermal Stress and Mechanical Debonding

Geothermal heat and fluid flow increase the wellbore temperature during typical production. The steel casing contracts in relation to the surrounding cement and formation as temperatures quickly equilibrate toward ambient geothermal gradients following a sudden shutdown. The casing-cement contact may debond as a result of this differential contraction, forming microannuli, which are tiny annular gaps that facilitate fluid migration into the formation. According to research, temperature changes cause unanticipated failure behaviors in the cement sheath, with thermally induced stress initiating casing-cement bond failures at the interface [10].

Chemical Degradation

The cement sheath is exposed to aggressive formation fluids in the absence of chemical inhibition programs and circulating fluids. Many reservoir formations include acidic gases, especially CO_2 and H_2S, which can dissolve in connate water to generate sulfurous and carbonic acids that attack regular Portland cement (OPC). Calcium carbonate (calcite) and calcium bicarbonate are produced by the carbonation of aqueous CO_2 and calcium silicate hydrate (C-S-H) phases in OPC, which gradually weakens the mechanical strength of the cement matrix and increases its permeability. In the presence of copious amounts of aqueous CO_2, low-carbon steel casings can corrode at rates as high as millimeters per year [12, 13].

Cement deterioration increases in high-acid fields with H_2S. According to studies, without protective additives, cement exposed to an acidic environment for 30 d under downhole circumstances can exhibit corrosion depths of up to 36.6 mm and strength loss rates of up to 32.1% [14].

Microannulus Formation and Gas Migration

The formation or growth of microannular channels is possibly the most operationally relevant effect of cement sheath erosion during a shutdown. According to research on underground gas storage (UGS) wells, which face conditions similar to conflict-driven shutdowns, conventional cement formulas have poor effectiveness under cyclic loading. During operational cycles, the radial stress within the cement sheath increased linearly from approximately 17 MPa to 24 MPa, creating microannuli at the interfaces between the cement casing and cement formation. Once formed, these microannuli allow high-pressure formation gases to migrate upward via the annular space, resulting in sustained casing pressure (SCP) at the wellhead [15].

Sustained Casing Pressure: The Primary Indicator of Integrity Loss

The most frequently observed and diagnostically significant symptom of well integrity failure is SCP, a phenomenon in which pressure is constantly rebuilt in an annular region after bleeding off. Annulus bleed-off, pressure monitoring, and corrective actions are used to manage the SCP under typical operating conditions. Several factors significantly increase the likelihood and severity of SCP development during a conflict-driven shutdown [2, 11]:

- Stopping the injection of chemicals that typically shield the tube and cement barrier systems, such as biocides, scale inhibitors, and corrosion inhibitors.
- The early detection of SCP development is prevented when monitoring systems are lost owing to damage, power failures, or staff evacuation.
- Section "*Cement Sheath Failure During Prolonged Shutdown*" describes the progressive deterioration of cement caused by chemical attacks and thermal cycling.

- Pressure accumulation that raises the differential pressure across the weakened barrier parts in shut-in reservoirs (covered in Section "*Sustained Casing Pressure: The Primary Indicator of Integrity Loss*") may exceed the burst or collapse limitations.

Owing to integrity failures, field data from oilfields worldwide show that actual well operational lifespans are limited to 7–25 years, falling considerably short of design objectives [3]. This degradation period is significantly accelerated in conflict areas owing to the lack of maintenance, which permits minor integrity flaws to spread unchecked.

Casing Integrity: Corrosion and Mechanical Failure

Casing structural integrity failures, including corrosion-induced wall thinning, connection leaks, and mechanical deformation, account for a significant proportion of well integrity failures. Field data from the US Gulf of Mexico showed that tubular failure occurred in 45% of the 14,297 wells under study, with casing leaks ranging from corrosion-related perforations to poor connection make-up [13, 16].

If a prolonged shutdown occurs without corrosion inhibition:

- External casing corrosion accelerates in the presence of corrosive formation brines containing dissolved CO_2, H_2S, and chloride.
- Particularly in waters with high concentrations of total dissolved solids, bicarbonate, and sulfate ions, internal casing surfaces exposed to stagnant produced water are vulnerable to galvanic attack and pitting corrosion.
- In deep, high-pressure wells, the loss of fluid column support during a shutdown can change the effective stress regimes, perhaps leading to casing collapse in weak formations or compaction-related casing shear in soft, overpressured zones [3].

In high H_2S environments (sour-service), stress corrosion cracking (SCC) and hydrogen-induced cracking (HIC), mechanisms by which tensile stress accelerates corrosion-initiated crack propagation, are significantly amplified [3]. The relationship between the mechanical stress state and corrosion is particularly subtle. As several reservoirs in the MENA region, particularly those in Iraq and Libya, have notable H_2S concentrations, these mechanisms are immediately pertinent.

Wellhead and Christmas Tree Integrity

The crucial mechanical interaction between the downhole well system and surface production facilities is represented by the wellhead and the Christmas tree. They contain the main isolation valves, such as the subsurface safety valve (SSSV) and surface safety valve (SSV), which serve as the final line of defense against uncontrolled wellbore blowouts. These surface-mounted components are vulnerable to additional risks in conflict situations.

- Physical harm caused by intentional sabotage, shrapnel, or blast overpressure.
- In the absence of climate-controlled housing, exposure to radiation, temperature fluctuations, and atmospheric weathering can cause the degradation of seals and elastomers.
- Scale accumulation in the actuators and valve seats makes it difficult to restart.
- Hydraulically operated safety valves become inoperable due to the loss of hydraulic control fluid.

One significant risk during field re-commissioning following a dispute is the inability of the surface safety valves to close in an emergency and open upon restart. In fast wartime evacuations, proper pre-shutdown valve preservation and exercise are crucial but seldom possible [11].

RESERVOIR BEHAVIOR DURING PROLONGED SHUTDOWN

Pressure Redistribution and Buildup

One of the most basic subsurface reactions that occur when a producing well is closed is the gradual accumulation of pressure within the drainage volume. The process of gradually equalizing pressure from the wellbore outward to the reservoir borders is known as the classical pressure buildup (PBU) test phenomenon, which was formalized by Horner (1951) and subsequently extensively developed in well-testing literature [17].

This accumulation finally reaches a static reservoir pressure under typical shut-in conditions (such as for a well test). However, the consequences of a prolonged shutdown caused by conflict are more complicated and uneven in space. There are several different pressure redistribution phenomena.

Wellbore Pressure Buildup

As input from the formation continues after shut-in, the flowing bottomhole pressure (FBHP), which is much lower than the average reservoir pressure during production, increases rapidly. The pressure in a homogeneous, single-zone reservoir approaches the static reservoir pressure exponentially. In theory, this pressure accumulation serves as a helpful pressure recharge that can enhance post-shutdown production rates upon restart by reducing the skin effect surrounding the wellbore [18].

However, minimal reservoir performance degradation should be anticipated for wells that were not severely damaged before shutdown, according to the reservoir pressure commentary literature [18]. Stronger wells may even exhibit sustained performance improvement as a result of pressure recharge in the drainage volume during the shut-in. However, this typically positive perspective is based on the lack of complicated variables listed below.

Wellbore Storage and Liquid Loading Effects

The abrupt stop of flow causes gas segregation within the wellbore in vertical wells that produce below the bubble point pressure or in wells with large wellbore fluid columns. The dissolved gas exsolves from the liquid column and migrates to the top of the casing, increasing the pressure. The liquid may be forced back into the producing formation by the ensuing gas pressure. This liquid backflow, which may contain precipitated and formed materials, is a well-established restart concern that can seriously harm the area around the wellbore [19].

Crossflow Between Layers

During a shutdown, wells that penetrate many producing layers with varying reservoir pressures, permeabilities, or fluid types are especially vulnerable to interlayer crossflow. When production stops, the FBHP is no longer maintained at a sufficiently low level to overcome the pressure differential between layers. Consequently, fluids from higher-pressure, lower-permeability zones move into lower-pressure, higher-permeability zones through the wellbore annulus or open perforations.

There are several detrimental effects of this crossflow:

- *Relative permeability blocking:* Gas invasion of water zones or water invasion of oil-producing zones lowers the effective relative permeability of the primary generated fluid, which may prevent flow upon restart.
- *Incompatible fluid mixing:* Inorganic precipitation may occur in the wellbore when water from several formation sources combines (see Section "*Inorganic Scale Deposition*"). Organic precipitates that obstruct near-wellbore pore spaces can be produced by combining asphaltic and paraffinic oils from various source layers.

Additionally, formation solids (sand and fines) may be forced into the wellbore by pressure equalization, filling perforations, and production tubing.

The finding that wells with reservoir pressures below 0.3 psi/ft (0.068 bar/m) are more likely not to resume production after shutdown, while those below 0.2 psi/ft (0.045 bar/m) face almost certain production loss, highlights the significance of this mechanism for conflict-driven shutdowns [4].

Formation Damage: Asphaltene and Wax Precipitation

The precipitation of organic particles, such as asphaltenes and paraffin waxes, inside the near-wellbore reservoir matrix and production tubing is possibly the most detrimental reservoir-side effect of an abrupt pressure-depleting shutdown.

Asphaltene Precipitation and Deposition

The heaviest and most polar component of crude oil is asphaltenes, which are polycyclic aromatic hydrocarbons with metallic components (Ni, V, and Fe) and heteroatoms (N, S, and O) in their structure. Resins that function as peptizing agents thermodynamically stabilize the asphaltenes in the crude oil matrix. This stability is susceptible to variations in temperature, pressure, and fluid composition; any disturbance that lowers the solubility parameter of crude oil may cause asphaltene flocculation and deposition [20].

The crucial trigger for a sudden shutdown is pressure drawdown, as asphaltene particles precipitate out of the crude oil matrix when the reservoir pressure falls below the asphaltene onset precipitation (AOP) pressure in the time leading up to shut down (and possibly during the restart attempt). These particles:

- They adsorb onto the surfaces of rock minerals, especially clays such as kaolinite, changing their wettability from water-wet to oil-wet, which is a basic deterioration of reservoir quality [21].
- Agglomerated nanoparticle assemblages and surface deposition are two ways to plug pore throats and reduce permeability.
- Deposits in the production tubing and perforations; in severe circumstances, asphaltene deposits have been shown in many fields to entirely choke a wellbore.

The most difficult organic flow assurance issue is asphaltene deposition, which can be practically irreversible at the reservoir scale. Chemical remediation is both technically and financially challenging once asphaltene deposits change the wettability of the pore surface and obstruct micropore throats [22]. In offshore fields, the economic effect of asphaltene issues has been estimated to exceed $100 million per occurrence.

Paraffin Wax Deposition

During a shutdown, paraffin wax—high-molecular-weight n-alkanes (usually > C18) that crystallize below the Wax Appearance Temperature (WAT)—deposits throughout the production system, from the area around the wellbore to the surface pipeline. Wax crystallization begins when crude oils with a high wax content reach and fall below their WAT when the temperature drops to ambient geothermal values after flow stops [23].

In contrast to asphaltene deposition, paraffin deposition is typically reversible; wax layers can be removed using aromatic solvents (e.g., xylene and toluene) or melted via heat treatment. However, in a conflict-driven shutdown, wax deposits can build up thicknesses and mechanical strength that make their removal exceedingly challenging owing to the prolonged lack of regular mechanical pigging, hot-oiling, or chemical inhibitor injection. Particularly difficult organic deposits are produced when asphaltene and wax co-precipitate, as is commonly observed in heavier crude oils [24].

Inorganic Scale Deposition

The precipitation of inorganic mineral scales is caused by the mixing of incompatible water streams, which is a common result of crossflow during shutdown (see Section "*Crossflow Between Layers*"). The most common and operationally significant scales in MENA oilfields include:

- When the CO_2 partial pressure decreases (as in a shut-in), calcium carbonate ($CaCO_3$) precipitates, changing the carbonate equilibrium and supersaturating the formation water relative to the calcite.
- When barium-rich formation brines combine with sulfate-containing injections or connate fluids, barium sulfate ($BaSO_4$) precipitates. With a Mohs hardness of 3.5, the $BaSO_4$ (barite) scale is incredibly hard and resistant to most chemical scale dissolvers.
- After pH shifts and temperature equilibration, iron sulfide (FeS), which is frequently found in H_2S-rich reservoirs, deposits in perforations, tubing, and the near-wellbore matrix.

Additional scale precipitation triggers are produced by pressure drops in the wellbore and the vicinity of the wellbore; the drop in pressure forces CO_2 out of solution, raising the pH and encouraging carbonate scale deposition. These minerals can crystallize in pore throats and perforation tunnels in stationary, unmonitored wells without scale inhibitor squeeze treatment, significantly lowering the injectivity and productivity indices needed for restart.

Clay Swelling and Migration

Significant permeability damage can result from water imbibition into clay-rich sandstone reservoirs during shutdown, especially in water-sensitive formations that contain swelling clays, such as smectite (montmorillonite). Water is absorbed into the rock matrix during shutdown, hydrating the expanding clay minerals when the capillary pressure gradient reverses (from the drainage to the imbibition mode). When a well is restarted, clay swelling can cause pore obstructions that significantly limit flow by reducing pore throat widths and mobilizing clay particles (fines migration) [25].

Sand inflow into the wellbore during shut-in-related backflow events can also occur in ductile and unconsolidated sand deposits, which are prevalent in shallow MENA reservoir sections. One well-known restart issue under these geological conditions is sand bridging inside production tubing or sand filters [4].

AGGRAVATING FACTORS IN THE ARMED CONFLICT CONTEXT

Loss of Monitoring and Early Warning Systems

The lack of real-time monitoring capability is a basic issue that is unique to conflict-driven shutdowns. Under typical conditions, flowmeters, temperature sensors, downhole gauges, and surface pressure gauges are used to continuously check the integrity of the well. Formation pressure buildups and falloffs are examined to find the reservoir pressure drop, skin deterioration, or barrier leaks. Continuous casing pressure monitoring enables the early detection of cement or casing integrity issues. All of these monitoring systems are concurrently rendered inoperable in crises by staff evacuation, power outages, and communication infrastructure damage [5, 11].

The literature specifically points out that, historically, reservoirs were not monitored during protracted shutdowns brought on by war or civil unrest because there was neither the financial incentive nor the technical capability to do so. This lack of monitoring has resulted in a fundamental lack of data required to assess the consequences of reservoir damage [18]. Planning for field re-commissioning is made much more difficult by this data gap, which endures even after disputes are resolved.

Interruption of Water Injection and Pressure Maintenance

The majority of major MENA oilfields, such as Libya's Waha and Sarir concessions and Iraq's Rumaila, Zubair, and West Qurna fields, depend on constant water injection to maintain reservoir pressure above the bubble threshold and sustain production rates. Electrical power, chemical treatment, pump maintenance, and expert operational supervision are all necessary for the water injection systems.

There are two main subsurface repercussions when water injections are suddenly stopped during a conflict.

- *Rapid reservoir pressure decline:* When pressure surpasses organic onset thresholds, dissolved gas is released, oil relative permeability decreases, and asphaltene/wax precipitation occurs because injected water is not used to replace generated fluids.
- *Water-oil contact (WOC) movement:* When pressure support is removed from bottom-water-drive reservoirs, water may seep into the oil column, changing saturation distributions in ways that may be difficult or impossible to undo.

This reliance was particularly highlighted by the Brookings Institution's analysis of Iraq's oil industry after the 2003 conflict: in the absence of water injection, field pressure dropped, leading to a decline rather than an increase in output; the relationship was characterized as a chicken-and-egg dependency between electricity and oil production.

Physical Infrastructure Damage

Wellheads, production manifolds, flowlines, processing facilities, and export terminals are all directly damaged by armed conflict. Over 700 Kuwaiti wellheads were purposefully destroyed during the 1990–1991 Gulf War, resulting in uncontrolled blowouts and oil burns that took years and billions of dollars to extinguish and clean up. Unregulated production has serious negative effects on the environment and subsurface, including the contamination of near-surface aquifers and possible reservoir depressurization from unregulated flows [5].

Integrity threats arise from physical damage to wellheads because exposed wellbore annuli allow water and ambient oxygen to enter, hastening the corrosion of the external casing. The main mechanical barrier against uncontrolled fluid release is removed when wellhead isolation valves are damaged or missing, leaving the wellbore open to the atmosphere. This is an urgent issue of well integrity in high-pressure reservoirs [8].

Beginning in 2011, Libya's civil war destroyed the nation's only LNG liquefaction facility and damaged many field production facilities, preventing investment, new development, and even basic maintenance for over ten years. As a prerequisite for any production recovery, Libya's National Oil Corporation (NOC) has frequently rehabilitated conflict-damaged fields. This procedure necessitates a thorough wellbore integrity assessment, equipment replacement, and infrastructure repair.

Loss of Chemical Treatment Programs

Under normal circumstances, continuous chemical injection programs are essential for preserving well integrity and the operability of production systems. These programs include corrosion inhibitors (usually film-forming amines and imidazolines), scale inhibitors (phosphonates and polymer compounds), biocides (glutaraldehyde and quaternary ammonium compounds), demulsifiers, and asphaltene inhibitors. All of these safeguards are simultaneously eliminated when all chemical injections are abruptly stopped during a conflict-driven shutdown.

The consequences include:

- Accelerated internal casing and tubing corrosion, particularly in the splash zone and at gas-liquid interfaces in shut-in wells, is a concern.
- Uncontrolled scale deposition in perforations, near-wellbore matrix, and production tubing.
- Microbiologically influenced corrosion (MIC) is driven by sulfate-reducing bacteria (SRB) proliferating in stagnant, unbiocided well fluids, which is particularly relevant in water-producing wells with high H_2S potential [3].
- Uncontrolled asphaltene and paraffin wax accumulation, as discussed in Section "*Formation Damage: Asphaltene and Wax Precipitation*"

WELL RE-COMMISSIONING AFTER CONFLICT: TECHNICAL PROTOCOLS AND CHALLENGES

Pre-Restart Well Assessment

A thorough well integrity assessment is required before any effort to resume production in a well that has experienced a conflict-driven shutdown. In accordance with the ISO 16530-1 and NORSOK D-010 guidelines for well re-commissioning, this assessment should employ an organized risk-based methodology, as shown in Table 1 [1, 8].

Well Kill and Preservation Operations

The first step in establishing well control for wells with impaired surface integrity (damaged wellheads, missing tree valves) is to kill the well with weighted kill fluid prior to any equipment modifications. To prevent aggravating formation damage, the choice of kill fluid type (drilling mud, $CaCl_2$ or NaCl brine, or specially designed finishing fluids) must consider compatibility with the reservoir rock and fluids [4].

Table 1. Recommended technical assessment activities and diagnostic methods for evaluating well integrity, reservoir condition, and surface infrastructure prior to field restart following prolonged unplanned shutdowns.

Assessment activity	Technical method	Primary objective
Wellhead pressure survey	Annular pressure monitoring; bleed-off test	Detect SCP; assess barrier status
Casing integrity test	Pressure integrity test (PIT); casing inspection log (CIL)	Identify corrosion, splits, or collapse
Cement evaluation	Cement bond log (CBL); variable density log (VDL); ultrasonic imaging tool (USI)	Assess zonal isolation; detect microannuli
Downhole camera/impression block	Wireline-conveyed tools	Identify tubular obstructions, fill, or damage
Reservoir pressure survey	Static bottomhole pressure gauge; buildup test (if feasible)	Determine current reservoir pressure vs. pre-shutdown
Fluid compatibility analysis	PVT analysis; scale tendency model	Assess precipitation risk on production restart
Surface equipment inspection	Visual + NDT inspection of wellhead, Xmas tree, and manifolds	Confirm the mechanical operability of isolation valves

For wells with intact wellheads but uncertain downhole integrity, a conservative operational sequence involves the following:

- Monitoring annular pressures for SCP buildup during a shut-in observation period.
- A pressure integrity test was conducted at the maximum anticipated shut-in tubing pressure (SITP) to verify the barrier competency.
- Injecting preservation fluids (corrosion inhibitor, biocide, scale inhibitor) as pickle treatments before extended re-shut-in if restart is to be deferred.

Production Restart Sequence

Restarting production after a prolonged conflict-driven shutdown carries significant risks of wellbore damage, surface equipment failure, and safety hazards to workers. A controlled, staged restart sequence should address the following:

- Initial low-rate production with choke management avoids rapid pressure drawdown, which could trigger organic solid precipitation or sand influx.
- Progressive rate escalation based on observed flowing bottom hole pressure trends, sand monitoring (desander measurements or downhole acoustic sensors), and fluid analysis for scale and asphaltene indicators.
- The resumption of chemical injection at startup or immediately pre-startup, with asphaltene inhibitor injection, is particularly critical for asphaltene-prone crude oils.
- Early water injection restart re-pressurizes the reservoir before producing at full rates, preventing gas evolution below the bubble point.

According to the literature [18], the remaining reservoir pressure, well fluid composition (asphaltene/wax content), completion type (single vs. multizone), and existing production infrastructure should all be considered when deciding which well to restart first. Since they have the lowest restart risk, high-pressure, single-zone, and non-asphaltic wells should be prioritized.

Challenges in Post-Conflict Restart: MENA Case Studies

Iraq

The oil industry in Iraq after the 2003 war serves as an example of the complete complexity of restarting a field after a conflict. Targeting pipelines, pumping stations, and power plants, the sabotage campaign made the environment unsuitable for investment and discouraged foreign oil corporations from sending workers and equipment to the region. Output recovery was delayed for years owing to a vicious loop caused by the reliance of power generation on oil output and water injection systems on electric power [5].

Owing to the depth and energy of the underlying reservoirs, wells in the large, high-pressure Rumaila and Zubair fields maintained significant pressure and production capacity, according to post-conflict assessments of Iraqi wells. In contrast, shallower fields suffer more severe depressurization and formation damage, necessitating lengthy workover programmes before commercial production can resume.

Libya

Perhaps the most well-documented case study of field shutdowns caused by violence and their effects in the modern era is Libya's. Before the 2011 civil war, crude oil production averaged over 1.6 million bbl/d. Since then, it has drastically fluctuated, sometimes reaching almost nothing, with each conflict adding layers of equipment deterioration, missed maintenance, and decreased production capacity. To counteract the decline from older fields, the NOC has frequently had to start new wells or repair those destroyed by violence, underscoring the irrevocable nature of some production losses caused by conflict [6].

Rehabilitating farms that local militias have blocked to gain political and economic clout has proven particularly difficult in Libya. Libya's production capacity has been irreversibly undermined by these shutdowns, which have occasionally lasted weeks or months and have resulted in formation damage and equipment degradation, such that production recovery to pre-shutdown levels was not always attainable.

MITIGATION STRATEGIES AND BEST PRACTICES

Pre-Conflict Contingency Planning

Preemptive preparation is the best way to mitigate the harm caused by conflicts. Conflict Shutdown Contingency Plans (CSCPs) that outline the following should be created and routinely practiced by operators in geopolitically sensitive areas:

- High-value, high-pressure wells are prioritized in well shutdown sequences to reduce formation damage.
- Pre-shutdown chemical squeeze treatments for all active wells apply scale inhibitors, corrosion inhibitors, and biocides into the near-wellbore formation to provide continuous protection during unattended periods.
- Wellbore preservation protocols include closing and locking all surface safety valves, securing tubing and annulus isolation barriers, and installing wellhead pressure gauges with data loggers capable of autonomous operation.
- Deployment of remote monitoring systems (satellite-linked wellhead pressure transmitters) that continue to acquire and transmit data even during personnel evacuation.
- Accelerated preventive maintenance schedules during periods of political tension to maximize the mechanical integrity of all barriers before a potential shutdown event.

Digital Monitoring and Remote Surveillance

Owing to advancements in digital well monitoring technologies, such as fiber-optic distributed temperature sensing (DTS), distributed acoustic sensing (DAS), satellite-connected downhole gauges, and autonomous wellhead monitoring units, it is now technically possible to maintain continuous subsurface surveillance even during personnel evacuation [15]. For operators in high-risk areas, deploying these systems before conflict escalation is essential.

Digital twin technology provides the potential for offline monitoring and predictive damage assessment during unattended shutdown periods, generating a continuously updated virtual model of the well system by integrating all available sensor data. This enables operators to plan appropriate remediation before re-entering the field [3].

Post-Conflict Well Integrity Standards

An organized, risk-tiered integrity assessment procedure in line with the ISO 16530-1 framework and NORSOK D-010 revision cycle should oversee the re-commissioning of wells after conflicts. Every well should be given a Risk Classification, which establishes the extent and order of integrity verification necessary before restarting and is based on reservoir pressure, fluid type, casing and cement age, and length of unattended shutdown [1, 8].

Regardless of the economic pressure to quickly restore output, thorough casing integrity tests, cement logs, and downhole tool runs should be performed before any production resumption for high-risk wells (such as high-pressure sour-service wells with prolonged unattended shutdowns). A comprehensive pre-restart integrity effort is significantly less expensive than a blowout or uncontrolled release from a well with an undiagnosed integrity issue.

DISCUSSION

During conflict-driven shutdowns, the combination of reservoir performance change and well integrity deterioration presents a compounding technical and financial burden on the operator. Cement microannulus development, casing corrosion, asphaltene precipitation, scale deposition, and clay swelling are examples of individual mechanisms that work in concert with one another. For instance, crossflow between zones caused by the loss of injection support introduces water into oil-producing intervals, destabilizing asphaltenes and starting scale precipitation, while cement microannuli produced by thermal cycling enable formation brines to contact the casing, accelerating external corrosion. The overall outcome is a decline in system integrity, which is far worse than the total failures of individual components [3, 11, 20].

Perhaps the most significant factor influencing the extent of the damage is the length of the unmanaged shutdown. Particularly in high-energy reservoirs with non-asphaltic crude oils, brief shutdowns of days to weeks, as observed in some conflict escalation events, usually permit full production recovery with minimal intervention. Long-term shutdowns, ranging from months to years, can cause cumulative harm that can permanently lower well and field output, thereby stranding reserves [5, 6, 18]. Examples include the Libyan conflict cycles and the post-invasion Iraq situation.

The strategic and geopolitical importance of subsurface technical integrity in conflict-affected fields is highlighted by the well-established observation that some of this production is not only halted but is physically locked away from ever being produced through the wellbore, permanently reducing the global supply [7]. This is not only a technical issue; it has significant ramifications for the global hydrocarbon supply, post-conflict economic rehabilitation, and energy security.

In terms of its economic and geopolitical importance, conflict-driven shutdown repercussions remain understudied. The main gaps in the literature are as follows: (1) there are few published case studies on the technical results of post-conflict well integrity assessments; (2) there are no systematic, quantitative field data on reservoir pressure decline and formation damage progression during unattended shutdowns, primarily because such data acquisition is impossible during active conflict; and (3) there are no validated predictive models for estimating the magnitude and reversibility of formation damage.

CONCLUSIONS

The technical literature on reservoir behavior and well integrity under abrupt, conflict-driven field shutdowns was compiled in this review. The main findings are:

- Cement sheath integrity is the most critically vulnerable well barrier element during prolonged, unattended shutdowns. Thermal cycling, chemical attack by CO_2 and H_2S, and cessation of chemical protection programs accelerate debonding, cracking, and microannulus formation, manifesting as sustained casing pressure, the primary indicator of well integrity failure.
- Reservoir behavior during extended shutdown is dominated by pressure buildup in single-zone systems (generally beneficial), but complicated by crossflow between multizone completions, organic solid precipitation (asphaltene, wax), inorganic scale deposition, and clay swelling in the near-wellbore environment.

- The conflict context introduces specific aggravating factors, such as loss of monitoring, cessation of water injection and pressure maintenance, interruption of all chemical programs, and potential physical infrastructure damage, which collectively accelerate damage mechanisms beyond what is experienced in economically motivated or planned shutdowns.
- Well re-commissioning after conflict must follow a rigorous, risk-tiered integrity assessment and controlled restart protocol to avoid blowout risk, formation damage escalation, and environmental harm.
- Pre-conflict contingency planning, including well-preservation treatments, remote monitoring deployment, and shutdown sequence optimization, is the most cost-effective strategy for minimizing post-conflict recovery time and cost.
- The loss of production capacity from conflict-driven shutdowns can be permanent and irreversible in a significant proportion of wells, with important implications for post-conflict energy sector reconstruction and global energy security issues.

The creation of validated predictive models for shutdown-induced formation damage, systematic post-conflict integrity assessment campaigns with public reporting, and incorporation of conflict risk into well integrity management frameworks for operators in geopolitically sensitive environments should all be prioritized in future research.

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