Extending Run Lengths in Naphtha Hydrotreater Feed/Effluent Exchangers: A Comprehensive Analysis of Fouling Mechanisms and Mitigation Strategies for Coker Naphtha Service

Section 1: The Coker Naphtha Fouling Challenge in NHT Units

1.1 Introduction to Coker Naphtha as a Challenging Feedstock

Naphtha Hydrotreater (NHT) units are essential for preparing feed for catalytic reformers by removing contaminants that poison the reforming catalyst.[1] While processing straight-run naphtha from crude distillation is a relatively straightforward operation, the introduction of cracked naphthas, particularly coker naphtha, presents a formidable challenge to unit reliability, efficiency, and run length. Coker naphtha is a product of delayed coking, a severe thermal cracking process designed to convert heavy vacuum residuum into more valuable, lighter products.[2] This thermal process fundamentally alters the molecular composition of the hydrocarbon stream, creating a product that is inherently unstable and highly prone to fouling.

The primary characteristics that define coker naphtha as a difficult feedstock for hydrotreating include [4]:

- **High Olefin and Diolefin Content:** Unlike straight-run naphtha, which is largely paraffinic, naphthenic, and aromatic, coker naphtha contains significant concentrations of olefins and, more critically, highly reactive conjugated diolefins. These unsaturated compounds are the primary precursors to polymerization and gum formation.[4]
- **Presence of Free Radicals:** The thermal cracking reactions that produce coker naphtha also generate free radicals, which can initiate polymerization chain

reactions even without external catalysts.[4]

- **Elevated Contaminant Levels:** Coker naphtha is laden with impurities that are detrimental to both the hydrotreating process and downstream units. Sulfur content can be up to 20 times higher than in straight-run naphtha, and nitrogen levels are also significantly elevated.[8] Furthermore, coker naphtha often contains unique contaminants like silicon (from silicone-based antifoam agents used in the coker drums) and various organo-metallic compounds, all of which can foul equipment and poison catalysts.[10]

The combination of these reactive species and contaminants makes coker naphtha a primary driver of fouling in the NHT feed/effluent (F/E) exchanger train. This fouling leads to significant operational penalties, including reduced heat recovery, increased fired heater duty, throughput losses, and ultimately, costly unscheduled shutdowns for cleaning.[4]

1.2 Primary Fouling Mechanisms in Coker Naphtha Service

The degradation of F/E exchanger performance in coker naphtha service is not caused by a single mechanism but by a combination of interacting physical and chemical processes. The three most common types of fouling are organic deposits (polymerization), inorganic particulates, and ammonium salts.[4]

Chemical Reaction Fouling (Polymerization and Coking)

This is the most aggressive and problematic fouling mechanism when processing coker naphtha. It is a temperature-dependent process that occurs on the feed side of the exchangers and can be described by a multi-step, free-radical chain reaction [12]:

1. **Initiation:** The process begins with the formation of a free radical. This can be triggered by the thermal decomposition of unstable molecules at elevated temperatures, but it is dramatically accelerated by the presence of initiators. Molecular oxygen, which can enter the system if feed tanks are not properly nitrogen-blanketed or if feeds are imported, is a particularly potent initiator, forming reactive peroxide radicals.[4] Other species common in refinery streams, such as disulfides and pyrrolic nitrogen compounds, can also initiate

polymerization.[13]

2. **Propagation:** Once formed, a free radical reacts with the double bond of a diolefin or olefin molecule, creating a new, larger radical. This new radical then reacts with another unsaturated molecule, propagating a chain reaction that forms long-chain, soluble polymers known as "gums".[6] This polymerization process becomes significant at temperatures above 350-450°F (177-232°C), a range easily reached and exceeded in the F/E exchanger train.[5]
3. **Deposition and Aging:** As the feed stream heats further, these soluble gums become less stable. They can precipitate out of solution, particularly if the feed vaporizes (the "dry point" phenomenon), or they can undergo further thermal degradation on hot tube surfaces. This aging process involves dehydrogenation and cross-linking, converting the sticky gums into a hard, brittle, and highly insulating layer of coke.[4]

The fouling potential of coker naphtha is not merely the sum of its individual components; it is a result of a powerful synergistic effect. The feed stream often contains a "perfect storm" of high diolefin concentrations, dissolved oxygen from storage, and iron sulfide particles from upstream corrosion.[4] The iron can act as a catalyst, accelerating the decomposition of peroxides into more free radicals, which in turn drives faster polymerization.[10] This catalytic, accelerated reaction explains why introducing a coker naphtha stream can cause fouling rates to increase exponentially, reducing run lengths from years to mere months or even days.[4]

Furthermore, the fouling process becomes a self-accelerating cycle. An initial layer of foulant, which has a much lower thermal conductivity than the tube metal, acts as an insulator.[15] To maintain the required rate of heat transfer, the temperature of the fluid film at the deposit surface (the "skin temperature") must increase.[4] Since the rate of chemical reaction fouling is highly dependent on temperature, this elevated skin temperature causes the polymerization and coking reactions to proceed even faster, leading to an exponential increase in the fouling rate over time.[22]

Inorganic Particulate Fouling

This mechanism involves the physical deposition of solid particles that are entrained in the naphtha feed. The most prevalent of these are corrosion byproducts, chiefly iron sulfide (FeS), which spalls from upstream carbon steel piping and equipment.[4] Other inorganic solids can include sand and silt, particularly if feedstocks are imported or stored in open-topped tanks.[4] While these particles can cause fouling on their own, their impact is magnified in coker naphtha service. The sticky organic polymers formed by chemical reactions act as a binder, trapping the inorganic particles and creating a hard, composite deposit that is extremely difficult to remove.[23] These particles also provide rough nucleation sites that promote the initial attachment of organic foulants to the heat transfer surface.

Salt Deposition (Crystallization Fouling)

Salt deposition is a distinct fouling mechanism that primarily affects the colder sections of the F/E exchanger train. It is most commonly observed on the reactor effluent side but can impact the overall performance of the entire exchanger. The high nitrogen content of coker naphtha is converted to ammonia (NH_3) in the hydrotreating reactor via hydrodenitrogenation (HDN) reactions.[10] Simultaneously, chlorides present in the feed (from incomplete desalting or other sources) are converted to hydrogen chloride (HCl). As the hot reactor effluent cools in the F/E exchangers, these two gases can react and precipitate, or desublimate, as solid ammonium chloride (

NH_4Cl) when the temperature drops below the salt's formation point.[4] Ammonium bisulfide (

NH_4HS) can also form from the reaction of ammonia with hydrogen sulfide (H_2S) and deposit in a similar manner.[27] This salt deposition can severely restrict flow paths and insulate heat transfer surfaces, contributing to the overall performance degradation of the exchanger train.

Section 2: Global Benchmarks and Performance Metrics for F/E Exchanger Cleaning

2.1 Establishing Time Between Cleanings (TBC) Benchmarks

Determining a single "average" time between cleanings (TBC) for NHT F/E exchangers in coker naphtha service is challenging due to the wide variability in feedstock quality, unit design, operating philosophy, and the extent of mitigation strategies employed. However, analysis of industry case studies and operational reports provides a clear range of performance benchmarks that can guide expectations and justify improvement initiatives.

In units processing a significant fraction of coker naphtha without robust mitigation measures, run lengths can be distressingly short. Severe fouling events, often triggered by a combination of high diolefin content and oxygen contamination, have forced unit shutdowns for exchanger cleaning after as little as **3 months** of operation.[20] A more typical scenario for a unit introducing a challenging coker stream, such as a light coker pentane/hexane cut, is a run length of

5-6 months before reactor pressure drop or heater limitations mandate a shutdown.[5]

For refineries that have implemented some level of operational control or basic chemical treatment, a more common TBC falls in the range of **11 to 18 months**.[20] While this is an improvement, it often does not align with the desired overall unit turnaround schedule, which is typically driven by catalyst life (2-4 years). This misalignment results in additional downtime and lost production opportunities solely for exchanger cleaning. Consequently, the goal for many refiners is to extend the F/E exchanger TBC to match the catalyst cycle, targeting a run length of

2 years or more.[20] Achieving this goal almost invariably requires a multi-faceted mitigation strategy, including advanced chemical treatment programs or hardware modifications.

The dramatic impact of coker naphtha is starkly illustrated by a case study of a hydrotreater that had operated successfully for over 30 years with minimal fouling issues. Upon the introduction of a light coker naphtha stream to meet new gasoline specifications, the unit's run length plummeted to just 5-6 months, demonstrating how quickly a stable operation can be compromised by a change in feed quality.[5]

Table 2.1 consolidates data from various industry sources to provide a practical benchmarking tool. It allows operators to compare their unit's performance against others with similar feed challenges and to see the quantifiable impact of various mitigation strategies.

Table 2.1: NHT F/E Exchanger Cleaning Intervals (Coker Naphtha Service): Industry Benchmarks and Case Studies

Case Study Reference	Feed Composition (% Coker Naphtha)	Initial TBC (months)	Mitigation Strategy Implemented	Achieved TBC (months)	Key Observation
Ecolab Case Study 2 [20]	Not specified, but severe fouling	3	Upgraded antifoulant/antipolymerant program	12+ (run extended)	A non-nitrogen blanketed feed tank caused a rapid fouling event, limiting the run to 3 months. The new chemical program extended the cycle significantly.
Ecolab Case Study 1 [20]	Mixture of straight-run and purchased coker naphtha	12 - 18	Upgraded antifoulant program	>24 (goal to align with turnaround)	New chemistry improved normalized heat transfer coefficient by over 60%, enabling alignment with the refinery's standard turnaround cycle.
Becht Engineering Case [5]	Heavy naphtha + diesel + coker	5 - 6	Addition of LCO to feed to prevent full	Run length extended (abated	Introduction of light coker naphtha caused

	pentane/hexane		vaporization	problem)	severe fouling, dropping run length from >30 years to 5-6 months.
Nalco Champion Case [18]	Straight-run + coker naphtha + purchased naphtha (oxygenated)	11	Advanced antifoulant treatment program	21+	The program extended the cycle length, reduced maintenance costs, and provided a significant economic return.

2.2 Monitoring Fouling Progression: KPIs and Their Limitations

Effective management of exchanger fouling requires diligent monitoring to track performance degradation, predict end-of-run conditions, and schedule cleaning activities proactively. Refiners rely on several key performance indicators (KPIs), often in combination with process simulation software.

- **Overall Heat Transfer Coefficient (U-value):** This is the most direct and sensitive measure of thermal fouling. The U-value is calculated from process temperatures and flow rates and trended over time. A decline in the normalized U-value (actual U-value divided by the clean U-value) is a direct indication of the buildup of fouling resistance (Rf) on the heat transfer surfaces.[25] The relationship is given by:
  Rf=Ufouled1–Uclean1
  where Ufouled is the current heat transfer coefficient and Uclean is the coefficient of the clean exchanger.
- **Pressure Drop (ΔP):** As deposits build up, they constrict the cross-sectional area for flow, leading to an increase in pressure drop across the exchanger.[15] While a critical parameter to monitor, especially for hydraulic limitations, pressure drop is often a lagging indicator of fouling. Significant thermal resistance can build up before a major increase in pressure drop is observed, particularly for thin, highly

insulating coke layers.[15]

- **Heater Inlet Temperature (HIT) and Fired Heater Duty:** From an operational and economic standpoint, this is the most critical KPI. The primary function of the F/E exchanger train is to recover heat from the reactor effluent to preheat the feed, thereby minimizing the energy required from the fired heater. As the exchangers foul, their ability to recover heat diminishes, causing the temperature of the feed entering the heater (HIT) to decrease. To compensate and maintain the required reactor inlet temperature (RIT), the fuel gas firing rate of the heater must be increased.[15] The run length of the exchangers is ultimately limited by the maximum firing capacity of the charge heater. Once the heater is maxed out, the only options are to reduce unit throughput or shut down for cleaning.[23]
- **Process Simulation and Modeling:** Modern refineries employ sophisticated process simulators like Aspen HYSYS, often coupled with rigorous heat exchanger design programs such as HTRI's SmartPM or Aspen EDR.[25] These tools use real-time plant data (temperatures, pressures, flows) to continuously calculate the performance of each exchanger in the network. By comparing the calculated "service" U-value to the theoretical "clean" U-value, the software can quantify the fouling resistance for each shell individually, allowing engineers to pinpoint which bundles are fouling the fastest and to predict when the heater will reach its limit.[25]

Section 3: Fouling Progression in Multi-Bundle Exchanger Trains (e.g., 8-Bundle Design)

In a typical NHT unit, the F/E heat exchange service is not performed by a single exchanger but by a train of multiple shell-and-tube exchangers arranged in series and sometimes in parallel (e.g., two parallel banks of four shells each, creating an 8-bundle system).[20] Understanding where and why fouling occurs within this train is critical for effective troubleshooting and mitigation. The progression of fouling is not random; it is dictated primarily by the temperature profile across the exchanger bank.

3.1 The Temperature Profile as the Primary Driver of Fouling Location

The F/E exchanger train operates in a counter-current fashion, where the cold naphtha feed enters the coldest shell and is progressively heated as it moves towards the hottest shell, while the hot reactor effluent flows in the opposite direction. This creates a steep temperature gradient, with each shell operating in a distinct temperature window.[15] Because the primary fouling mechanisms—polymerization, coking, and salt deposition—are highly sensitive to temperature, different bundles will foul preferentially via different mechanisms.[4]

3.2 Hot-End Fouling (Hottest Bundles): Polymerization and Coking

When processing coker naphtha, the feed-side of the hottest bundles in the train (e.g., shells 7 and 8 in an 8-bundle series) are almost invariably the first to experience significant fouling. These are the exchangers where the feed temperature is highest, typically exceeding the 350-450°F (177-232°C) threshold required to initiate the rapid polymerization of diolefins.[5]

The high wall temperatures in these shells, heated by the hottest reactor effluent, create ideal conditions for chemical reaction fouling. Any oxygen present in the feed will have its full catalytic effect, and the high skin temperatures will accelerate the conversion of soluble polymers into hard, insulating coke deposits on the tube surfaces.[4] This fouling manifests as a rapid degradation of the heat transfer coefficient (U-value) in these specific shells, forcing the downstream fired heater to compensate for the lost heat recovery.

3.3 The Critical "Dry Point" and its Impact

A key design and operational consideration in many NHT units is the need to ensure the feed is fully vaporized before it enters the radiant section of the fired heater. This is done to prevent liquid droplets from impinging on the hot heater tubes, which would lead to severe, localized coking and potential tube failure.[17] This complete vaporization, or "dry point," is often designed to occur within one of the hotter F/E exchanger shells.[10]

The location of this phase change is a zone of intense and rapid fouling. As the last of the liquid naphtha vaporizes, any soluble gums and polymers that were held in the liquid phase are forced to precipitate. The liquid phase acts as a solvent, and its disappearance leaves the polymers with nowhere to go but onto the heat transfer surfaces.[5] This phenomenon is compounded by the fact that as the liquid vaporizes, its velocity decreases, reducing the turbulent scrubbing effect that helps keep surfaces clean.[40]

The significance of the dry point was highlighted in a case study where the addition of a light coker pentane/hexane stream to the feed caused a shift to total vaporization within the exchangers. This change was directly correlated with a catastrophic increase in fouling and a reduction in run length from over 30 years to just 5-6 months.[5] This demonstrates that managing the location and nature of the phase change is paramount. As hotter shells foul, they transfer less heat, pushing the dry point further down the train into previously cooler shells, thereby propagating the severe fouling problem.

3.4 Cold-End Fouling (Coldest Bundles): Salt Deposition and Polymer Precipitation

The coldest bundles in the train (e.g., shells 1 and 2) are susceptible to different fouling mechanisms driven by lower temperatures.

- **Effluent-Side Salt Deposition:** The most common issue in the cold end is the deposition of ammonium salts on the *effluent* side of the tubes. As the hot, contaminant-laden reactor effluent cools, its temperature can fall below the desublimation point of ammonium chloride (NH4Cl) and ammonium bisulfide (NH4HS). These salts then precipitate out of the gas phase directly onto the tube internals, forming a solid insulating layer that impedes heat transfer and increases pressure drop.[24] This is a well-known issue, particularly when processing high-nitrogen coker naphthas.[10]
- **Feed-Side Polymer Precipitation:** While the rate of temperature-driven polymerization is low in the colder shells, they can still experience feed-side fouling. High-molecular-weight polymers that were formed in upstream storage tanks or during transport can have limited solubility in the cold naphtha feed. As the feed enters the first exchanger, these pre-formed gums can precipitate out of solution and deposit on the surfaces.[24] Corrosion products like iron sulfide are also most likely to deposit in the first shell they encounter.

Table 3.1 provides a generalized map of where different fouling mechanisms are likely to dominate in a multi-bundle exchanger train. This serves as a valuable diagnostic tool: by identifying which exchangers are showing the most performance degradation, engineers can infer the most likely root cause of the fouling.

Table 3.1: Fouling Mechanisms and Locations in a Multi-Bundle NHT F/E Exchanger Train

Exchanger Shell(s)	Typical Feed Temperature Range	Dominant Feed-Side Fouling Mechanism	Dominant Effluent-Side Fouling Mechanism	Primary Impact
Hot End (e.g., last 2 shells)	> 200°C (> 392°F)	**Chemical Reaction Fouling:** Diolefin polymerization, coking. **Dry Point Deposition:** Precipitation of soluble gums at the point of full vaporization.	Minimal (effluent is superheated vapor)	Severe degradation of heat transfer coefficient (U-value).
Mid-Train (e.g., middle 4 shells)	100 - 200°C (212 - 392°F)	**Chemical Reaction Fouling:** Polymerization of most reactive species. **Particulate Fouling:** Deposition of FeS and other solids.	**Condensation Fouling:** Fouling can occur as effluent begins to condense.	Moderate degradation of U-value and increasing pressure drop (ΔP).
Cold End (e.g., first 2 shells)	< 100°C (< 212°F)	**Particulate Fouling:** Deposition of FeS, corrosion products. **Polymer Precipitation:** Drop-out of	**Salt Deposition:** Crystallization of NH4Cl and NH4HS as effluent cools below desublimation	Degradation of U-value and significant increase in effluent-side ΔP.

		pre-formed gums from cold feed.	point.	

Section 4: Strategic Mitigation: Extending Run Lengths and Managing Heater Capacity

Addressing the severe fouling challenge posed by coker naphtha requires a comprehensive, multi-layered strategy. No single solution is universally effective; rather, a combination of proactive feed management, optimized operations, targeted chemical treatment, and strategic hardware upgrades is necessary to maximize run length and manage the critical constraint of fired heater capacity. The following sections outline a tiered approach to these solutions, progressing from low-cost operational changes to major capital investments.

4.1 Feed Management and Pre-Treatment (The First Line of Defense)

The most effective way to mitigate fouling is to prevent the foulant precursors from entering the F/E exchangers in the first place.

- **Oxygen Exclusion:** Given that dissolved oxygen is a powerful initiator for polymerization, its exclusion is paramount. The best practice is to feed coker naphtha directly from the upstream coker unit's fractionator to the NHT, avoiding intermediate tankage where air contact can occur.[6] If storage is unavoidable, all tanks containing cracked stocks must be rigorously nitrogen-blanketed to prevent oxygen ingress.[4] This applies not only to the coker naphtha itself but to any other feed component blended with it, as oxygen contamination from one stream can catalyze polymerization in the entire blend.[5]
- **Feed Filtration:** To combat inorganic particulate fouling, the installation of high-efficiency filters on the combined feed stream is essential. Cartridge or sand filters with a fine pore size, typically in the 1-5 micron range, are effective at removing corrosion products like iron sulfide, as well as sand and silt from imported feedstocks.[4] Removing these solids eliminates potential nucleation sites

for organic deposition and reduces the overall volume of foulant.

- **Feed Composition Control:** The composition of the coker naphtha itself can be managed to reduce its fouling tendency. Refiners have found that increasing the initial boiling point (IBP) of the coker naphtha cut can be beneficial, as this reduces the concentration of the most volatile and highly reactive C5 and C6 diolefins.[4] Conversely, introducing very light, highly olefinic streams like coker pentane/hexane can be disastrous, as it can lower the feed's boiling point and shift the critical "dry point" into the F/E exchangers, leading to severe polymer deposition.[5]

4.2 Operational Best Practices (Leveraging Existing Assets)

Operators can make several adjustments to unit operation to leverage hydraulic forces and process conditions to minimize fouling.

- **Maintain High Fluid Velocity:** Fouling is a battle between deposition forces and removal forces. Maintaining a high fluid velocity on the feed side (which is typically routed through the tubes for this reason) increases the fluid shear stress at the tube wall. This hydraulic force helps to scrub the surface, making it more difficult for deposits to adhere and grow.[4] While higher velocity increases pressure drop, operating at low velocities is often a false economy, as it leads to higher tube wall temperatures and creates stagnant conditions that promote deposition.[4]
- **Inject "Soaker" Hydrogen:** A widely adopted and effective practice is the injection of a small amount of hydrogen gas (often termed "soaker hydrogen," in the range of 50-200 SCFB) into the liquid feed well upstream of the first F/E exchanger.[13] While this amount of hydrogen may not be sufficient to induce significant hydrogenation at the low temperatures of the cold-end exchangers, it provides crucial physical benefits. The addition of the gas increases the total volume and velocity of the fluid, enhancing turbulence and shear stress for better scouring. It also creates a two-phase flow regime that helps to fluidize and sweep away any solid particles, preventing them from settling and initiating a deposit layer.[13]
- **Manage Two-Phase Flow in Heater:** It is critically important to avoid feeding a two-phase mixture to the fired heater. Any entrained liquid droplets will coke on the hot tube surfaces, leading to fouling that can cause tube overheating and failure.[17] This operational constraint underscores the importance of maintaining

the F/E exchanger train's performance. As the exchangers foul, they fail to vaporize the feed completely, increasing the risk of liquid carryover to the heater and forcing a throughput reduction.

4.3 Chemical Treatment Programs (A High-ROI Intervention)

When feed management and operational adjustments are insufficient, a well-designed chemical treatment program is a powerful and cost-effective tool. These programs use a cocktail of specialized additives injected into the feed to disrupt the fouling process at multiple points.[42]

- **Antifoulant Chemistry Components:**
    - **Antipolymerants (Free-Radical Scavengers):** These are the core of the treatment for coker naphtha. They are designed to react with and neutralize the free radicals that initiate and propagate polymerization, effectively stopping the formation of gums at its source.[6]
    - **Dispersants:** These are long-chain organic molecules with a polar "head" and a non-polar "tail." The polar head attaches to the surface of foulant particles (both organic polymers and inorganic solids like FeS), while the non-polar tail keeps the particle suspended in the hydrocarbon bulk fluid. This prevents particles from agglomerating and depositing on equipment surfaces.[17]
    - **Metal Deactivators:** These additives are chelating agents that bind to dissolved metal ions, particularly iron, rendering them chemically inert. This prevents the metals from catalytically accelerating the decomposition of peroxides and subsequent polymerization reactions.[42]
- **Effectiveness and Economic Justification:** A properly selected and applied antifoulant program can yield dramatic results. Case studies from multiple refineries demonstrate that these programs can successfully extend exchanger run lengths from a baseline of 11-12 months to over 21-24 months, allowing cleaning to be aligned with scheduled turnarounds.[18] The economic benefits are substantial, arising from increased throughput, reduced energy consumption (lower heater firing), and avoided maintenance costs. Reported return on investment (ROI) for these programs frequently exceeds 300%, with documented annual savings in the range of $700,000 to $1.5 million per unit.[30] It is crucial, however, to conduct a thorough root cause analysis, including deposit analysis, to ensure the chemical program is tailored to the specific fouling mechanisms occurring in the unit, as misapplication can lead to limited success.[5]

4.4 Advanced Hardware and Design Solutions (Capital Projects)

For refineries facing chronic, severe fouling from a high percentage of coker naphtha in the feed, operational and chemical solutions may only be partially effective. In these cases, capital investment in advanced hardware provides a more permanent and robust solution.

- **Diolefin Saturation Reactor (DSR):** This is widely regarded as the definitive solution to polymerization fouling in NHTs.[5] The DSR is a small, separate guard reactor installed upstream of the F/E exchanger train. It operates at a relatively low temperature, typically 300-450°F (150-232°C), and contains a hydrotreating catalyst.[6] At these mild conditions, the extremely reactive conjugated diolefins are selectively hydrogenated to less reactive mono-olefins. This removes the primary polymerization precursors from the feed *before* it enters the hot F/E exchangers where they would otherwise polymerize. Technology licensors like Topsoe and Axens consider a DSR to be a standard design feature for any new hydrotreater intended for coker naphtha service.[6] Case studies have shown that retrofitting a DSR onto an existing unit has completely resolved repeated, severe fouling episodes that could not be controlled by other means.[5]
- **Fouling-Resistant Heat Exchangers:** Replacing conventional, segmentally-baffled shell-and-tube (S&T) exchangers with modern, fouling-resistant designs can provide a step-change improvement in performance and run length.
    - **Welded Plate Heat Exchangers (PHEs):** Technologies like the Alfa Laval Compabloc or Packinox utilize stacks of corrugated metal plates instead of tubes. This design creates a highly turbulent, uniform flow path with no stagnant "dead zones" where foulants can accumulate.[40] The high shear stress constantly scrubs the heat transfer surfaces, resulting in heat transfer coefficients that are 2 to 3 times higher than conventional S&T exchangers and dramatically lower fouling rates. Operational reports indicate these exchangers can run for over three years in hydrotreater service with negligible fouling.[40] Their superior thermal efficiency also allows for much closer temperature approaches, significantly reducing the amount of heat required from the fired heater, which directly addresses the key operational constraint and lowers energy costs.[40]

    - **Helixchanger™ Heat Exchangers:** This technology modifies the conventional S&T design by replacing standard segmental baffles with quadrant-shaped baffles arranged at an angle. This induces a continuous helical flow path on the shell side, eliminating the large recirculation eddies and low-velocity zones that are inherent sources of fouling in traditional designs.[34] This near-plug flow condition has been demonstrated to extend exchanger run lengths by a factor of two to three in fouling refinery services.[34]

The decision to pursue a capital solution requires a holistic economic analysis. While antifoulant programs offer an attractive operational expenditure (OPEX) solution with high ROI, they represent a recurring cost and may not provide complete protection in the most severe services. A capital project like a DSR or an exchanger upgrade has a high initial cost (CAPEX). However, this investment can be justified by evaluating the total lifecycle cost, which includes the elimination of perpetual antifoulant costs, the value of improved energy efficiency (lower fuel gas consumption), the elimination of frequent cleaning costs, and the increased revenue from higher unit reliability and throughput. The economic benefit of an advanced exchanger, for example, extends beyond the hardware itself to "spin-off" savings from a smaller required heater, smaller recycle gas compressor, and reduced plot space, which can account for the majority of the total project savings.[47]

Section 5: Advanced Cleaning Technologies and Scheduling

While mitigation strategies are focused on prevention, fouling will inevitably occur to some degree, necessitating periodic cleaning. The choice of cleaning technology and the scheduling strategy have a significant impact on turnaround duration, cost, and the subsequent run length of the unit.

5.1 Offline Cleaning Methods: A Comparative Analysis

Offline cleaning requires the exchanger to be taken out of service and typically involves removing the tube bundle for access.

- **High-Pressure Water Blasting (Hydroblasting):** This is the most traditional and

widely used method. It employs high-pressure water jets (10,000 to 40,000 psi) delivered via lances or robotic systems to mechanically dislodge and remove foulant deposits.[48]
  - **Advantages:** It is a well-understood technology available from many contractors and is effective on a wide range of hard deposits.
  - **Disadvantages:** It is labor-intensive, requires pulling the bundle, and poses safety risks associated with high-pressure water. A major drawback is its often incomplete effectiveness; hydroblasting may not reach deep into the center of a large tube bundle with sufficient force, and it can struggle with the tenacious bond between coke and the tube surface. This often leaves a residual foulant layer, resulting in a cleaning effectiveness of only about 85%.[50] It also generates large volumes of contaminated wastewater that require treatment and disposal.
- **Chemical Cleaning (Offline Circulation):** This method involves circulating a chemical solvent through the exchanger, either in-situ or after removal to a dedicated cleaning bay. The solvent is chosen to dissolve the specific foulant present.[50] For example, an acid solution like citric acid can be used for iron sulfide scale, while an organic solvent like toluene or a specialty formulation can be used for polymeric deposits.[52]
  - **Advantages:** It can be performed without pulling the tube bundle, reducing mechanical work. It can also target specific chemical bonds in the foulant, potentially achieving a better clean than mechanical force alone.
  - **Disadvantages:** Its success is entirely dependent on selecting the correct solvent for the deposit composition. An incorrect solvent will be ineffective.[53] The process can be slow, and incomplete cleaning poses a significant risk: partially dissolved foulants can break free upon startup and travel downstream, plugging the top of the reactor bed.[52] The process also generates large volumes of hazardous chemical waste.
- **Ultrasonic Cleaning:** This advanced technology represents a significant improvement over traditional methods. The tube bundle is immersed in a large tank filled with a cleaning solution (often just water with a mild detergent), which is then energized with high-frequency sound waves.[54]
  - **Advantages:** The process of cavitation—the rapid formation and collapse of microscopic bubbles—creates intense but localized energy that scrubs every surface of the bundle, including the hard-to-reach interior. This results in a superior level of cleanliness, often restoring the exchanger to a "like-new," zero-fouled condition (approaching 100% effectiveness).[50] It is safer than hydroblasting and dramatically reduces water consumption (by over 75%) and waste generation.[55]

  - **Disadvantages:** It is a specialized service that requires the bundle to be transported to a dedicated ultrasonic cleaning facility.

The choice of cleaning method has a direct and often underestimated impact on the subsequent operating cycle. An incomplete cleaning, typical of hydroblasting, leaves behind a residual fouling layer. This not only means the unit starts up with an immediate performance deficit but also that the rough, active surface of the remaining deposit provides ideal nucleation sites for new foulants to adhere, accelerating the rate of re-fouling.[32] In contrast, a superior clean, such as that achieved by ultrasonics, restores a smooth, passive surface, which can significantly extend the time until the next cleaning is required. Therefore, an economic evaluation of cleaning methods must consider the total lifecycle cost, including the impact on the next run length, not just the initial cost of the cleaning service.

5.2 Online and In-Situ Cleaning Strategies

To avoid costly shutdowns, several techniques have been developed to clean exchangers while the unit remains in operation.

- **Online Chemical Cleaning:** This is a proactive maintenance strategy to restore performance without a full outage.
  - **Segmented Cleaning:** In systems with parallel banks of exchangers, one bank can be isolated from the process and bypassed. A specialized chemical solvent is then circulated through the offline bank to clean it. Once clean, it is returned to service, and the next bank can be taken offline for cleaning. This allows for the sequential restoration of performance across the entire train while the unit continues to operate at a potentially reduced rate.[59]
  - **True Online Cleaning:** This highly specialized technique involves injecting a proprietary, high-solvency chemical (e.g., ZymeFlow's Rezyd-HP®) directly into the live process feed stream upstream of the exchangers.[59] This is done as a short-duration, periodic treatment (e.g., for one hour every 4-8 weeks). The chemistry is designed to fluidize and disperse deposits without negatively impacting downstream catalysts or product quality. Case studies show this approach can provide significant, immediate improvements in heat transfer (U-value improvements over 70%) and has enabled units to avoid unplanned shutdowns for several years.[60]
- **Other In-Situ Techniques:**

    - **Effluent Water Wash:** For removing ammonium salt deposits on the effluent side of the cold-end exchangers, a continuous or intermittent wash with oxygen-free water is a common and effective practice. The water is injected into the reactor effluent stream at a point where the temperature is above the salt's desublimation point, allowing it to dissolve the salts as they form and carry them out with the separator boot water.[24]
    - **Steam-Air Decoking / Controlled Burn:** For heavy coke deposits, a controlled burn using a mixture of steam and air can be performed in-situ to oxidize and remove the carbonaceous material.[41] This is an effective but complex procedure requiring careful control of temperature and oxygen concentration.

Section 6: Synthesis and Recommendations

6.1 Summary of Findings

The fouling of Naphtha Hydrotreater feed/effluent exchangers is a severe and multifaceted operational challenge, particularly when processing unstable coker naphtha feeds. The analysis reveals several key conclusions:

- The root cause of the most aggressive fouling is **chemical reaction fouling**, specifically the free-radical polymerization of diolefins present in coker naphtha. This process is dramatically accelerated by the presence of dissolved oxygen and catalyzed by common contaminants like iron sulfide.
- Fouling progression in multi-bundle exchanger trains is predictable and **driven by the temperature profile**. The hottest feed-side bundles foul first and most severely due to polymerization and coking, while colder bundles are more susceptible to salt deposition on the effluent side. The "dry point" where the feed fully vaporizes is a critical zone for intense polymer deposition.
- Industry benchmarks for **time between cleanings (TBC)** vary widely, from as low as 3-6 months in unmitigated cases to a more typical 12-18 months. The primary operational goal is to extend this TBC to align with multi-year catalyst cycles, thus maximizing unit availability.

- The ultimate operational constraint imposed by fouling is the **maximum firing capacity of the charge heater**. As exchangers foul, heat recovery declines, forcing the heater to work harder until it reaches its limit, at which point throughput must be cut or the unit shut down.
- A wide spectrum of mitigation strategies exists, ranging from low-cost operational improvements to high-return chemical treatment programs and high-cost, permanent hardware solutions. The most effective strategies address the problem at its source by removing foulant precursors or preventing their reaction.

6.2 Tiered Recommendation Framework

A successful strategy to manage F/E exchanger fouling and extend run length should be implemented in a tiered fashion, starting with the most accessible, lowest-cost options and progressing to more capital-intensive solutions as required by the severity of the problem and economic justification.

Tier 1: Immediate, Low-Cost Actions (Operational Discipline)

These actions focus on leveraging existing assets and implementing operational best practices to minimize the introduction and formation of foulants. They should be considered the foundation of any fouling mitigation program.

1. **Implement Rigorous Feed Management:**
    - **Oxygen Exclusion:** Mandate nitrogen blanketing for all tanks storing cracked naphtha or any streams blended with it. The best practice is to route coker naphtha directly from the coker to the NHT, bypassing intermediate storage entirely.[6]
    - **Feed Filtration:** If not already present, install and diligently maintain high-efficiency (1-5 micron) filters on the combined NHT feed to remove inorganic particulates like iron sulfide.[4]
2. **Optimize Unit Operations:**
    - **Maximize Feed Velocity:** Review the exchanger design and operating data to ensure feed velocity is maintained at a level that promotes high shear stress, balancing the benefits of scouring against pressure drop constraints.[4]

   - **Install/Optimize Soaker Hydrogen:** Implement or optimize the injection of soaker hydrogen upstream of the F/E exchangers to increase velocity and fluidize particles.[13]
3. **Enhance Performance Monitoring:**
   - Utilize process simulation tools to trend the fouling resistance (Rf) or normalized heat transfer coefficient (U-value) for *each individual exchanger shell*, not just the overall train. This allows for early detection of localized fouling and better diagnosis of the root cause.[25]

Tier 2: Mid-Term, Operational Expenditure (Chemical Treatment)

If Tier 1 actions are insufficient to meet run length targets, a targeted chemical treatment program offers a high-return-on-investment solution.

1. **Conduct a Root Cause Analysis (RCA):** Before implementing a chemical program, perform a thorough RCA. This must include collecting and analyzing foulant deposits from the exchangers to identify their chemical composition (e.g., organic polymer, FeS, salts). This analysis is critical for selecting the correct chemical additives.[15]
2. **Implement a Multi-Component Antifoulant Program:** Partner with a reputable chemical vendor to design and trial a program that includes a combination of:
   - **Antipolymerants** to inhibit gum formation.
   - **Dispersants** to keep particles suspended.
   - **Metal Deactivators** to neutralize catalytic metals.[26]
3. **Justify and Monitor the Program:** Justify the operational expenditure based on a clear ROI calculation, weighing the chemical cost against the value of increased throughput, energy savings from reduced heater firing, and avoided cleaning costs. Continuously monitor exchanger performance to verify the program's effectiveness.[30]

Tier 3: Long-Term, Capital Expenditure (Permanent Hardware Solutions)

For units with chronic, severe fouling that cannot be fully managed by Tier 1 and 2 strategies, or for new unit designs and major revamps, permanent hardware solutions offer the highest level of reliability.

1. **Install a Diolefin Saturation Reactor (DSR):** For any hydrotreater with a significant and consistent coker naphtha diet, the installation of a DSR is the most robust and definitive solution to polymerization fouling. By removing the reactive diolefins at low temperatures, it eliminates the primary fouling mechanism at its source.[5]
2. **Upgrade to Fouling-Resistant Heat Exchangers:** During a major revamp or for a grassroots unit, a holistic economic analysis should be performed to evaluate replacing conventional S&T exchangers with advanced, fouling-resistant designs like Welded Plate Heat Exchangers (PHEs) or Helixchangers.[34] The justification should not only consider the extended run length but also the significant "spin-off" capital and operating cost savings associated with higher thermal efficiency, such as a smaller fired heater and reduced energy consumption.

6.3 Concluding Remarks

The management of Naphtha Hydrotreater feed/effluent exchanger fouling in coker naphtha service is a complex but solvable challenge. It requires a shift from a reactive mindset of "run until fouled, then clean" to a proactive, integrated strategy of prevention and mitigation. By combining diligent feed management, optimized operations, targeted chemical treatments, and strategic investments in advanced hardware and cleaning technologies, refiners can successfully break the cycle of premature fouling. This comprehensive approach will lead to longer unit run lengths, improved energy efficiency, enhanced reliability, and ultimately, greater profitability.

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