TECHNICAL ARTICLE

Calcium Sulfonate Complex Grease

Chemistry, microstructure, formulation, manufacturing, performance, and application engineering

By Khash

A technical expansion of the accompanying Khash briefing video

Scope note

This article explains the engineering principles of calcium sulfonate complex (CSC) grease. It is not a substitute for a finished-product data sheet, original-equipment-manufacturer requirement, safety data sheet, or application qualification. Performance belongs to the complete formulation and manufacturing process, not to the thickener-family name alone.

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Abstract

Calcium sulfonate complex grease is a technically distinctive lubricant because the sulfonate system is not merely a passive soap thickener. An overbased calcium sulfonate concentrate contains surfactant-stabilized basic calcium species and calcium carbonate; controlled conversion transforms amorphous carbonate into a predominantly calcite-rich dispersed phase, while calcium salts of hydroxy fatty acids and other complexing components tune the network. The resulting material can combine high dropping point, strong mechanical stability, water resistance, wet-corrosion control, and extreme-pressure or antiwear capability. Those advantages are real but conditional. Base-oil viscosity, conversion state, particle morphology, complexing chemistry, residual moisture, additive interactions, homogenization, and field contamination determine whether a product pumps, replenishes a contact, resists washout, or instead stiffens, churns, starves a bearing, or becomes incompatible with the grease already in service. This article develops the chemistry-to-performance chain, explains manufacturing and quality-control levers, interprets the principal ASTM methods without overstating what they prove, compares CSC with other grease families, and presents a practical qualification and troubleshooting framework.

Keywords: *calcium sulfonate complex; overbased sulfonate; calcite conversion; lubricating grease; rheology; water contamination; tribofilm; corrosion; pumpability; compatibility*

> **Executive engineering conclusion.** CSC is best understood as a process-engineered particulate/soap/surfactant network in oil. Its strongest application case is usually severe wet, corrosive, high-load service where a qualified product can exploit its cohesive structure and alkaline calcium chemistry. Its weakest case is an application selected from dropping point or NLGI grade alone, especially where low-temperature pumping, high-speed churning, grease replenishment, or mixed-grease compatibility governs reliability.

Contents

1. Introduction and scope

Calcium sulfonate complex grease has moved from a specialized corrosion-protective material into a broad class of premium industrial greases. The attraction is straightforward: one formulated product can show high dropping point, resistance to mechanical working, resistance to direct water spray or washout, strong rust protection, and useful load-carrying performance. In steel, pulp and paper, mining, marine, construction, wet processing, and other severe environments, that combination can simplify lubricant selection and reduce the number of additives otherwise needed to create a balanced grease. Industry reviews and peer-reviewed studies support these characteristic tendencies, but they also show substantial dependence on composition, processing, temperature, and contamination state [3-8].

The thickener name does not define a single chemical recipe. Commercial products may differ in overbased sulfonate feedstock, carbonate concentration, total base number, base oil, calcite conversion, complexing acids, borate or phosphate content, tackifier, solid lubricants, antioxidants, corrosion inhibitors, friction modifiers, and manufacturing history. Two products both labeled "calcium sulfonate complex, NLGI 2" can therefore have materially different yield stress, apparent viscosity, oil release, low-temperature torque, water response, wear protection, and compatibility. The correct unit of engineering evaluation is the finished grease from a controlled manufacturing process.

This article uses "CSC" for calcium sulfonate complex grease and "overbased calcium sulfonate" for the oil-soluble/dispersed concentrate from which the thickener structure is developed. It distinguishes intrinsic chemical tendencies from product-specific performance. Patent examples are cited to illuminate process logic, not as universal manufacturing recipes. Laboratory methods are discussed as controlled comparisons, not as automatic predictions of field life. This distinction is especially important for dropping point, four-ball tests, oxidation tests, and grease-family compatibility charts, all of which are commonly overinterpreted [1,2,11-24].

1.1 Five propositions that prevent most selection errors

- **NLGI grade is consistency, not performance.** The worked penetration range says how readily a cone penetrates a worked grease under ASTM D217 conditions. It does not by itself state pumpability, leakage, film formation, bearing life, water resistance, or maximum speed [1].
- **Dropping point is a transition indicator, not a service-temperature rating.** ASTM D2265 explicitly warns that, particularly above 200 degrees C, dropping point should not be treated as the upper operating temperature [2].
- **Water resistance and water contamination are different problems.** A grease can resist being physically washed away yet absorb or retain water in a way that changes yield stress, flow, replenishment, corrosion behavior, and low-temperature mobility [4-6].
- **Thickener-family compatibility charts are only screening tools.** Compatibility is an interaction between two finished products. ASTM D6185 evaluates exact mixtures at several blend ratios because hardening, softening, oil separation, or dropping-point changes may be ratio-dependent [24].
- **The process creates the product.** Conversion state, crystal morphology, water activity, acid-base balance, heating profile, mixing intensity, and finishing are not incidental production details; they determine the network that the application experiences [8-10].

2. Grease architecture: what the product actually is

A lubricating grease is a structured lubricant in which a thickener network immobilizes a large fraction of base oil while still allowing oil to be released and replenished at the lubricated contact. The grease reservoir outside the Hertzian contact is semi-solid; the material entering a rolling or sliding contact is transformed by shear, pressure, temperature, and surface interactions. The engineering task is therefore not merely to make a grease "stay in place." It is to balance retention, flow, oil release, bleed-back, adhesion, channeling, and reworkability.

Conventional soap greases are often described as fibrous networks of metal carboxylate. That picture is only partly suitable for CSC. Microscopy and rheological studies describe a particulate or platelet-rich structure associated with converted calcium carbonate and sulfonate, together with calcium soaps or other complexing salts [4,6,8]. The network behaves as a concentrated, interacting dispersion rather than as a simple bundle of long fibers. This distinction helps explain why some CSC products show strong resistance to shear softening, why water can increase rather than decrease measured stiffness, and why apparent viscosity may be high even when cone penetration places the product in a familiar NLGI grade.

The product can be viewed as four coupled subsystems: (1) the continuous base-oil phase; (2) converted calcite-rich particles and residual colloidal carbonate; (3) calcium sulfonate and calcium carboxylate or other complexing species at interfaces and in the load-bearing network; and (4) dissolved or dispersed additives. None operates independently. A more viscous base oil can improve film thickness but worsen low-temperature mobility. Higher network density can improve leakage control but increase churning. More polar chemistry can improve surface affinity yet alter additive solubility. Greater water uptake can preserve apparent cohesion while impeding grease transport.

Table 1. Functional architecture of a finished CSC grease.

Subsystem	Primary function	Main formulation/process levers	Failure risk when misbalanced

Subsystem	Primary function	Main formulation/process levers	Failure risk when misbalanced
Base oil	Provides the fluid film, heat transport, and most viscous drag.	Oil chemistry, viscosity at operating temperature, viscosity index, volatility, solvency.	Starvation or wear if too light; heat, torque, poor pumping or channeling if too heavy.
Converted carbonate/sulfonate structure	Creates yield stress, consistency, water resistance, adhesion, and a reservoir of calcium-rich solids.	Overbased feedstock, conversion promoter, water, acid-base ratio, temperature, residence time, shear.	Underconversion, over-thickening, coarse particles, unstable consistency, poor reproducibility.
Complexing salts	Tune network efficiency, mechanical stability, pumpability, dropping behavior, and surface chemistry.	12-hydroxystearic acid (12-HSA), short-chain acids, borate, phosphate, calcium source, stoichiometry.	Brittle/hard structure, softening, corrosive residuals, additive antagonism, processing sensitivity.
Additive package	Controls oxidation, wear, scuffing, corrosion, tack, friction, and special approvals.	Chemistry, dosage, order of addition, solids dispersion, thermal exposure during manufacture.	Precipitation, filter blockage, seal attack, degraded water performance, excessive friction or deposits.

3. Calcium sulfonate chemistry, overbasing, and conversion

3.1 Neutral calcium sulfonate and amphiphilic structure

A calcium sulfonate molecule contains a polar sulfonate head associated with calcium and one or more oil-compatible hydrocarbon groups. This amphiphilic architecture enables the material to stabilize polar inorganic species in a nonpolar oil medium. In a neutral sulfonate, the calcium content is near the stoichiometric amount required to neutralize sulfonic acid groups. In an overbased sulfonate, the concentrate contains substantially more basic calcium than this stoichiometric neutralization alone would require. That excess is commonly present as calcium carbonate and related basic species dispersed within reverse-micelle-like aggregates [8].

Total base number (TBN) is frequently used to characterize overbased sulfonate feedstocks because it expresses acid-neutralizing capacity in milligrams of potassium hydroxide equivalent per gram. TBN is not, however, a direct measurement of calcite fraction, particle size, conversion state, or thickening efficiency. Two concentrates with similar TBN can differ in surfactant architecture, carbonate morphology, diluent oil, calcium distribution, and conversion response. Formulators must therefore qualify a feedstock by both chemical and process performance rather than purchase on TBN alone.

3.2 Overbasing and the dispersed carbonate reservoir

Overbasing is produced by reacting sulfonate chemistry with a calcium base and carbon dioxide under conditions that generate an oil-dispersed reservoir of calcium carbonate. The sulfonate system stabilizes nanometer-scale basic material in the hydrocarbon medium. Industry descriptions commonly distinguish relatively small neutral-sulfonate aggregates, larger overbased amorphous-carbonate aggregates, and substantially larger converted crystalline particles, although exact dimensions depend on method and formulation [8]. The important engineering point is not a single size number; it is the controlled transition from a colloidal, weakly thickening state to a crystalline, network-forming state.

$$2\ R\text{-}SO_3H + Ca(OH)_2 \rightarrow (R\text{-}SO_3)_2Ca + 2\ H_2O$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Simplified mass-balance relationships. Real overbased concentrates contain a distribution of sulfonate, carbonate, hydroxide, water and interfacial species.

3.3 Conversion: amorphous carbonate to calcite-rich structure

The decisive manufacturing step is usually called conversion. A controlled amount of water and one or more polar promoters are introduced, together with heat, mixing, and an acid-base environment that allows amorphous calcium carbonate to reorganize into crystalline calcium carbonate. A calcite-rich morphology is generally desired for CSC grease; unwanted polymorphs or poorly controlled crystal growth can produce inferior rheology or excessive thickener demand. Industry sources describe calcite as producing relatively plate-like or wafer-like particles, whereas aragonite is more needle-like [8]. These descriptors are useful conceptual models, but actual commercial microstructures are polydisperse and contain interfacial organic material.

Conversion is not simply “adding water.” Water activity, not only total water, controls nucleation and transport. The promoter package, temperature ramp, residence time, agitation, carbon dioxide availability, acid addition, and concentration of the reacting mixture can alter nucleation density and crystal growth. Too little conversion can leave an underdeveloped network and poor consistency. Excessive local water, acid, or poor mixing can create agglomeration, nonuniform conversion, corrosive residues, or an abrupt viscosity rise that defeats heat and mass transfer. Patents disclose a wide variety of sequences and temperature windows, which confirms that the process is formulation-specific rather than a universal recipe [9,10].

Fourier-transform infrared spectroscopy, X-ray diffraction, microscopy, ash or thermogravimetric analysis, moisture measurement, and rheological or penetration testing may all be used to monitor conversion. Patent literature proposes specific infrared bands for amorphous and converted carbonate, but those wavelengths and ratios require calibration to the supplier's feedstock, instrument, sampling method, and finished formulation. A spectral "conversion number" is therefore most valuable as an internal statistical-process-control metric tied to physical properties, not as a universal acceptance criterion.

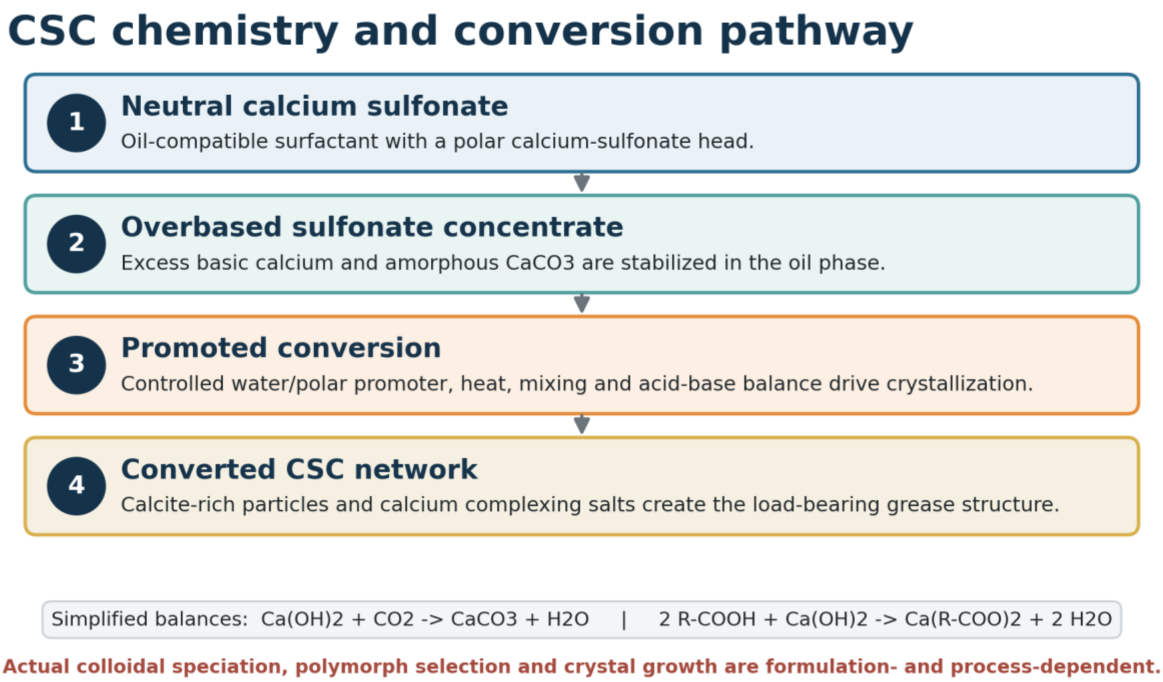

Figure 1. Conceptual chemistry and conversion pathway for CSC grease. The schematic is explanatory and not a molecular-scale representation.

> **Process caution.** Published patents are valuable for understanding sequencing, promoters, conversion logic and analytical controls. They are not safe plug-and-play manufacturing instructions. Exact process conditions depend on reactor geometry, heat-transfer area, agitation, water removal, raw-material composition, pressure control, and hazard analysis.

4. Complexing chemistry and the commercial formulation continuum

4.1 "Simple" and "complex" calcium sulfonate greases

A simple calcium sulfonate grease relies predominantly on the converted overbased sulfonate system for thickening. Historically, this could require a high proportion of sulfonate concentrate, with corresponding cost, density, and pumpability implications. A calcium sulfonate complex grease introduces additional calcium salts, commonly derived from 12-HSA and one or more co-acids or inorganic complexing species, to improve thickener efficiency and tune the network [8]. The term "complex" indicates a multi-component thickener chemistry; it does not specify a single stoichiometry or guarantee a particular performance level.

12-HSA is especially useful because its hydroxylated fatty chain forms calcium soap structures that can interact with the converted sulfonate/carbonate phase while remaining compatible with hydrocarbon oils. Short-chain carboxylic acids, boric species, phosphates, acetates, or other components may be used to adjust conversion, high-temperature structure, pumpability, water response, and mechanical stability. The choice and order of addition influence both chemistry and morphology. A component that improves penetration yield can worsen low-temperature flow; a species that strengthens the network can reduce oil release or increase shear heating.

$$2\ R\text{-}COOH + Ca(OH)_2 \rightarrow Ca(R\text{-}COO)_2 + 2\ H_2O$$

Simplified calcium-carboxylate formation. Hydroxy fatty acids and co-acids can form multiple calcium salts and mixed structures under process conditions.

Table 2. Practical distinction between simple and complex calcium sulfonate grease. Family-level tendencies only.

Attribute	Simple calcium sulfonate grease	Calcium sulfonate complex grease	Engineering implication
Primary thickening basis	Converted overbased sulfonate/carbonate system.	Converted sulfonate/carbonate plus calcium carboxylates and/or other complexing salts.	"Complex" is a structural family, not a fixed recipe.
Typical thickener demand	Often comparatively high in historical formulations.	Frequently lower because the mixed thickener is more efficient.	Lower demand may improve cost, base-oil fraction and pumpability, but formulation controls the result.
Rheology	Can be highly particulate and stiff.	Can be tuned over a broader range through complexing chemistry and finishing.	Do not infer apparent viscosity from NLGI grade.
Water behavior	Inherently strong sulfonate affinity and cohesive structure.	Often retains strong water resistance, while co-thickener chemistry modifies uptake and stiffness.	Water washout and water-contaminated rheology must both be measured.
Performance package	May rely strongly on intrinsic alkaline/calcium chemistry.	More formulation latitude for AW/EP, oxidation, corrosion, food-grade or specialty requirements.	Finished-product test data remain decisive.

4.2 Thickener content is not a quality score

Industry overviews have reported that older simple calcium sulfonate greases could contain on the order of 40-50 percent thickener-related concentrate, whereas complex products may use materially less, often in a broad range around 15-35 percent depending on definition and formulation [8]. Those numbers should not be turned into a universal specification. "Thickener content" can be reported on different bases, and the overbased sulfonate concentrate itself contains diluent oil. A lower percentage may indicate efficient structure, or it may indicate a soft product with insufficient robustness. A higher percentage may improve cohesion, or it may impose excessive apparent viscosity and churning. Performance must be normalized to the actual product and duty cycle.

5. Manufacturing, process control, and quality assurance

5.1 Representative process sequence

A representative CSC manufacturing sequence begins with a base-oil charge and overbased calcium sulfonate concentrate, followed by controlled introduction of promoters and reactants that initiate conversion. Complexing acids and calcium base are added in a defined order to form calcium salts. The batch is heated to complete reaction and remove water, then finished through additional oil dilution, cooling, additive incorporation, milling or homogenization, deaeration, and filtration as appropriate. Some patent examples separate conversion and complexing into distinct stages; others integrate them. The practical objective is consistent microstructure, not allegiance to a single sequence [9,10].

The conversion and saponification portions of the batch are strongly coupled to heat and mass transfer. As viscosity rises, mixing becomes less uniform and local temperatures can diverge from the bulk reading. Water removal can be limited by surface renewal, vapor handling, foaming, and reactor pressure. A process that performs well in a pilot kettle may not scale linearly to a large reactor because impeller power per unit volume, tip speed, circulation pattern, heat-transfer area per unit volume, and vapor disengagement change. Scale-up should therefore preserve relevant dimensionless and transport relationships rather than merely copy time and temperature set points.

5.2 Critical process parameters and their signatures

Table 3. Manufacturing variables that directly influence CSC grease structure and field behavior.

Process parameter	What it controls	Common off-target signature	Useful control/verification
Overbased feedstock identity and lot	Carbonate reservoir, surfactant stabilization, TBN, diluent oil and conversion response.	Unexpected conversion time, penetration drift, coarse grain, changed water response.	Supplier fingerprint, TBN, Ca/ash, FTIR, incoming conversion trial, retained sample.

Process parameter	What it controls	Common off-target signature	Useful control/verification
Water/promoter amount and addition rate	Nucleation, transport, conversion uniformity and viscosity rise.	Underconversion; local gel; foaming; agglomerates; prolonged dehydration.	Metered addition, reactor mass balance, vapor profile, in-process FTIR/XRD correlation.
Acid-base stoichiometry	Complexing salt formation, residual alkalinity, corrosion and network efficiency.	Free acid or excess lime, unstable consistency, corrosive odor/residue, poor additive response.	Raw-material assay, acid/base number, pH of extract where meaningful, stoichiometric reconciliation.
Temperature-time history	Reaction completion, water removal, crystal growth, additive survival and oxidation.	Soft batch, excessive hardening, darkening, odor, deposit tendency, poor repeatability.	Calibrated bulk and wall temperature, heat-input profile, endpoint criteria, oxygen control.
Mixing and shear	Dispersion, local concentration, heat transfer and final particle/agglomerate size.	Graininess, pockets of soft/hard grease, filter blockage, inconsistent penetration.	Power draw, impeller condition, recirculation sample, microscopy, homogenizer gap/control.
Cooling and finishing	Recrystallization, network setting, oil distribution and final rheology.	Post-production penetration drift, oil bleed, high apparent viscosity, lot-to-lot variability.	Controlled cooling curve, delayed QC, worked penetration, rheology, storage stability.
Residual moisture and aeration	Pumpability, oxidation, false volume, corrosion and water-induced stiffness.	Foam, density variation, hardening in service, corrosion, inconsistent package fill.	Karl Fischer or validated moisture method, vacuum/deaeration, density, headspace control.

5.3 A rational quality-control architecture

Finished-grease quality control should be layered. Release tests such as worked penetration, dropping point, appearance, and elemental or infrared fingerprinting are necessary but insufficient. A robust control plan links incoming raw-material identity to in-process conversion indicators and to performance-sensitive final properties. Statistical process control is most useful when the selected metrics have known causal relationships to customer failure modes.

- **Incoming controls:** identity, TBN or alkalinity, calcium/ash, viscosity of diluent, acid assay, water, additive purity, and a supplier change-notification system.
- **In-process controls:** time-temperature profile, addition mass balance, mixing power, endpoint spectroscopy or diffraction, water-removal profile, and intermediate consistency.
- **Release controls:** D217 worked penetration, appearance and texture, dropping point, oil separation, apparent viscosity or pumpability, corrosion and water performance where critical, and retained-sample fingerprint.
- **Periodic validation:** four-ball or other tribology tests, oxidation, elastomer compatibility, bearing or rig testing, water-contaminated rheology, and application-specific pump-loop testing.
- **Change control:** requalification after significant changes in sulfonate source, base oil, complexing chemistry, additive package, reactor, homogenizer, batch size, or thermal sequence.

6. Rheology, mechanical stability, and lubrication mechanics

6.1 Yield stress and shear thinning

Grease does not behave as a Newtonian oil. At low stress it can respond as a viscoelastic solid; above a characteristic yield region it flows, and its apparent viscosity normally decreases as shear rate increases. A common engineering representation is the Herschel-Bulkley relation, in which shear stress is the sum of a yield term and a shear-rate-dependent term. The model is empirical, and fitted parameters depend on instrument geometry, wall slip, sample history, temperature, and test protocol, but it provides a useful vocabulary for comparing products.

tau = tau_0 + K*(gamma_dot)^n
apparent viscosity = tau / gamma_dot

tau_0 = fitted yield stress; K = consistency index; n < 1 indicates shear thinning. Protocol and pre-shear must be reported with the result.

A high yield stress may reduce leakage and help resist water displacement, but it can increase the pressure required to move grease through a centralized system and can inhibit replenishment into a starved bearing track. A low yield stress can improve flow and relubrication but permit purge, leakage, or channeling. The optimum is determined by the system: line length and diameter, pump and injector design, ambient temperature, bearing free volume, speed, relubrication interval, and purge path.

6.2 Oscillatory rheology and structural strength

Small-amplitude oscillatory shear separates the elastic storage modulus, G-prime, from the viscous loss modulus, G-double-prime. In the linear viscoelastic region, a grease with G-prime greater than G-double-prime behaves predominantly as a weak solid. An amplitude sweep identifies the strain at which the structure begins to break down; a frequency sweep probes time-scale dependence. Temperature ramps show whether the network weakens, strengthens, or undergoes irreversible change. These tests are more sensitive to structure than cone penetration, but they are not yet interchangeable across laboratories unless geometry, gap, roughness, loading, pre-shear, rest time, and thermal history are standardized.

In a peer-reviewed study of two CSC greases, dry samples showed little shear softening under the applied protocol, consistent with a particle-dominated structure that is difficult to irreversibly break [4]. That finding should not be converted into "all CSC greases are shear-proof." Complexing chemistry, conversion, base oil, temperature, contaminants, and shear mode matter. ASTM D1831 roll stability and extended worked penetration provide practical directional indicators, but ASTM itself cautions against assuming a precise correlation with service behavior [17].

6.3 Penetration, pumpability, and bearing mechanics

ASTM D217 worked penetration places a grease into an NLGI consistency grade after a defined working procedure. NLGI 2 corresponds to a worked penetration of 265-295 tenths of a millimeter [1]. This familiar number is useful for dispenser and housing design, but products with the same grade can have very different low-shear viscosity, yield stress, thixotropic recovery, apparent viscosity at pumping shear rates, and low-temperature torque. Pump sizing should therefore rely on pressure-flow data or an appropriate apparent-viscosity method such as ASTM D1092, supplemented by a loop or injector test when long lines, low ambient temperature, or narrow passages are critical [18].

Inside a rolling bearing, excessive grease volume or excessive viscous resistance causes churning and heat. As the bearing runs, grease is displaced from the rolling track and forms reservoirs near cage or shoulder regions. Reliable lubrication depends on controlled replenishment of base oil and small quantities of worked grease back toward the contact. A grease that is too mobile may leak; one that is too stiff, too adhesive, or strongly hardened by water may fail to replenish. High dropping point cannot compensate for poor replenishment mechanics.

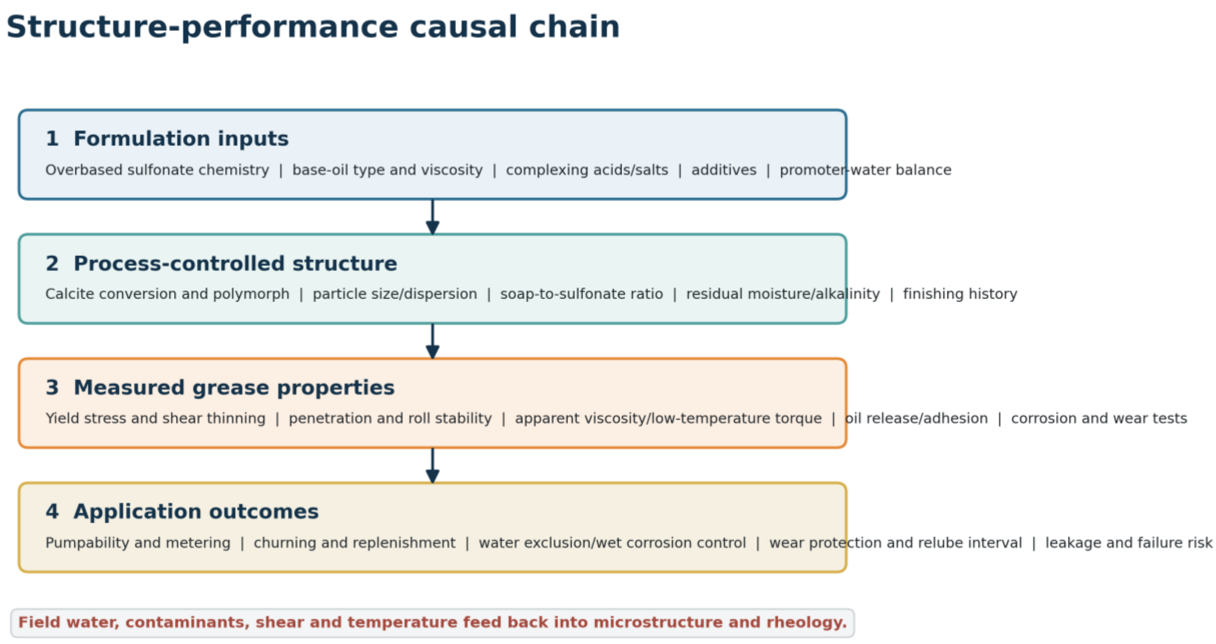

Figure 2. Structure-performance map. Field behavior emerges from coupled formulation, processing, rheology, and contamination effects.

7. Water interaction: resistance, absorption, and hidden failure modes

7.1 Four different questions are often collapsed into "water resistance"

Water exposure must be decomposed into distinct mechanisms. Washout asks whether water removes grease from a bearing-like assembly. Spray-off asks whether a direct jet strips grease from a surface. Corrosion testing asks whether the grease protects steel under controlled wet conditions. Water-contaminated rheology asks how incorporated water changes flow and structure. These mechanisms are related but not equivalent. ASTM D1264, D4049, D1743, and D6138 address different parts of the problem and should not be substituted for one another [13-16].

CSC grease often performs strongly in washout, spray-off, and wet-corrosion tests because the calcium sulfonate system is surface-active, alkaline, cohesive, and strongly associated with the carbonate-rich structure. This is one reason CSC is attractive for mills, mines, marine equipment, wet conveyors, and processing plants. Yet retained water can still change the grease. A product may remain physically present while becoming too stiff to pump or replenish, or while trapping a brine that drives localized corrosion. “It did not wash away” is therefore not a complete pass criterion.

7.2 Water-induced stiffening and inverse-micelle structures

Peer-reviewed work comparing several grease types found that the tested CSC grease stiffened as water content increased, while tested lithium, lithium-complex, and polyurea greases tended to soften under the same study conditions [5]. Subsequent microstructural work associated CSC water uptake with large water-containing inverse micelles or related domains within the grease [4,6]. In the shear-stability study, wet CSC samples formed a homogeneous water-containing microstructure and showed increased stiffness rather than the classical shear-softening response observed in many fibrous soap systems [4].

The magnitude of water uptake reported in a laboratory maximum-uptake protocol can be very high for a particular CSC product [5]. Such a number is not a target capacity and should not be generalized to all CSC formulations. Real equipment is exposed to free water, emulsified water, condensation, brine, process liquor, cleaning chemicals, and solids, under simultaneous shear and thermal cycling. The relevant acceptance limits are application-specific: corrosion rating, pump pressure, injector delivery, bearing temperature, torque, oil release, and post-exposure consistency at the actual contamination level.

> **Critical nuance.** Water absorption can help a grease remain cohesive and resist physical washout, but it is not automatically beneficial. Incorporated water can raise yield stress and apparent viscosity, reduce flow through lines, impair bearing replenishment, increase low-temperature torque, and retain dissolved salts. Evaluate both retention and post-contamination function.

7.3 A practical wet-service qualification matrix

Table 4. Water-service qualification should separate removal, corrosion, and rheology mechanisms.

Exposure mechanism	Recommended evidence	What a pass should demonstrate	Common blind spot
Direct washout	ASTM D1264 at relevant test temperature; component test if geometry is unusual.	Grease mass loss remains within the product/application limit.	No proof of corrosion control, rheology after water uptake, or field life.
High-pressure spray	ASTM D4049 and, where relevant, adhesion test on actual surface.	Grease film resists displacement by a directed water jet.	A tacky residue can pass adhesion yet pump or replenish poorly.
Condensation / static wet bearing	ASTM D1743 or OEM variant.	No unacceptable rust in a wet tapered-roller-bearing environment.	Does not reproduce saltwater, dynamic operation, or process chemicals.
Dynamic wet corrosion / brine	ASTM D6138 with selected water medium.	Controlled corrosion under rotating bearing conditions.	Rating remains laboratory-specific; chemistry of actual brine may differ.
Incorporated water	Rheology, worked penetration, apparent viscosity, pump loop, oil separation and corrosion after defined water addition.	The contaminated grease remains deliverable and lubricating, not merely cohesive.	Many product data sheets report no water-contaminated transport data.
Immersion / process liquor	Application-specific coupon, seal, bearing or rig test with actual fluid and temperature.	Chemical compatibility, corrosion control, adhesion and replenishment together.	Clean water tests may miss surfactant, pH, salt and solvent effects.

8. Tribology and corrosion-control mechanisms

8.1 Boundary-film formation is formulation-specific

CSC grease can provide strong antiwear and extreme-pressure performance through several overlapping mechanisms: the base oil supports hydrodynamic or elastohydrodynamic film formation where speed permits; polar sulfonate and calcium carboxylate species adsorb at surfaces; calcite-rich particles can enter or influence boundary contacts; alkaline components neutralize acidic species; and tribochemical reaction products form under pressure and temperature. The relative importance of each mechanism changes with contact type, steel composition, sliding ratio, temperature, surface finish, and additive package.

Wang and co-workers reported good room-temperature and 150 degrees C friction and wear performance for an experimental CSC formulation and identified calcium carbonate/oxide, iron oxide, boron-containing species, and, when molybdenum dithiocarbamate was used, molybdenum sulfide and oxide in the tribofilm [3]. That study demonstrates plausible tribochemical pathways; it does not mean every commercial CSC grease produces the same film. The experimental formulation included barium- and calcium-containing soap chemistry and a specific additive package, so its X-ray photoelectron spectroscopy results should be read as formulation evidence, not a universal fingerprint.

A 2024 study varying overbased calcium and magnesium sulfonates in castor-oil-based complex greases likewise showed that rheological and tribological performance shifted with sulfonate identity and ratio, and that the resulting films contained a mixture of calcium, magnesium, iron, carbonate, sulfate, oxide, and other species [7]. The broader lesson is that “sulfonate” is an active formulation variable. Feedstock chemistry and additive balance can change both bulk rheology and surface reaction.

8.2 Interpreting four-ball results

ASTM D2596 four-ball EP testing reports measures such as weld point and load-wear index under a standardized sliding contact. ASTM D2266 evaluates wear-preventive characteristics under lower-load conditions. These tests are useful for formulation screening and lot comparison, but the standards caution that a direct service correlation is not established [11,12]. A high weld point does not prove suitability for a rolling bearing, slow oscillating pin, open gear, electric-motor bearing, or heavily contaminated bushing. The contact mechanics, replenishment, temperature, and failure mode are different.

For critical applications, four-ball data should be combined with geometry-relevant evidence: SRV or reciprocating wear for oscillatory sliding; FZG-type gear scuffing or wear where gears dominate; fretting tests for micro-motion; rolling-contact fatigue or bearing rig tests where bearing life is critical; and component tests with actual seals, metallurgy, surface finish, water, dust, and relubrication. A product can look excellent in one boundary test yet fail because it cannot reach the contact.

8.3 Corrosion protection

Calcium sulfonates have a long history in rust-preventive formulations. Their polar head groups support surface affinity, the hydrocarbon tail maintains oil compatibility, and overbased chemistry provides alkalinity that can neutralize acidic contaminants. In a grease, the cohesive network also creates a physical barrier to water and oxygen. These features explain the strong wet-corrosion reputation of CSC products, but corrosion performance can be degraded by free acid, chloride contamination, poor conversion, incompatible additives, or water domains that retain electrolyte against the surface.

A robust corrosion program distinguishes static condensation from dynamic water exposure and clean water from saltwater or process fluid. ASTM D1743 and D6138 are useful standard anchors, but actual media may contain chlorides, sulfides, alkalis, acids, cleaners, or microbial products. Where failure consequences are high, coupon and bearing tests should use the real contaminant at realistic temperature and concentration. Elastomer and coating compatibility should be tested in parallel because a grease that protects steel can still swell a seal or soften a coating.

9. Formulation engineering: base oils, additives, and trade-offs

9.1 Base-oil selection

The base oil is the primary determinant of fluid-film viscosity, viscous drag, low-temperature mobility, volatility, and much of the oxidation response. Mineral oils offer cost-effective solvency and broad availability. Polyalphaolefin can improve viscosity-temperature behavior and low-temperature performance but may require solvency management. Esters can improve polarity, lubricity, and biodegradation potential but introduce hydrolysis, seal, and oxidation considerations. Other synthetic fluids can be used in specialized formulations, but compatibility with the sulfonate/complexing system and additives must be demonstrated.

Base-oil viscosity should be selected from contact speed, load, geometry, operating temperature, and desired film thickness, not from grease family. A slow, heavily loaded, wet bushing may need a relatively high-viscosity oil, whereas a high-speed rolling bearing may overheat on the same product. The speed factor often expressed as n times d-sub-m is a useful screening parameter for rolling bearings, but supplier limits are product- and bearing-specific. Oil viscosity at the actual stabilized bearing temperature is more meaningful than the nominal grade at 40 degrees C.

Solvency matters because CSC contains polar and inorganic components. A change in base-oil chemistry can alter additive solubility, tackifier efficiency, oil separation, seal compatibility, and the wetting of calcite-rich particles. Blends are often used to balance viscosity index, solvency, low-temperature flow, and cost. The blend must be qualified after the full thermal process; an oil that is stable as a neat fluid can respond differently in a high-alkalinity, metal-containing grease matrix.

9.2 Additive design and antagonism

Because CSC already contains a high concentration of surface-active calcium chemistry and dispersed mineral material, conventional additive packages cannot be assumed to behave exactly as they do in lithium soap grease. Antioxidants, sulfur-phosphorus EP agents, phosphorus antiwear compounds, molybdenum friction modifiers, solid lubricants, corrosion inhibitors, metal deactivators, tackifiers, dyes, and polymers can adsorb on particles, compete at metal surfaces, react with residual alkalinity, or change conversion and thickening if added too early.

Additive order and temperature exposure are therefore part of formulation design. Thermally sensitive antioxidants or friction modifiers are generally added after high-temperature processing, but late addition requires adequate dispersion. Solid additives can improve load-carrying or emergency lubrication while increasing filtration difficulty, density, sedimentation risk, and abrasive contamination sensitivity. Tackifiers may improve adhesion and water spray-off yet worsen low-temperature pumping, injector refill, and bearing churning. The final balance should be judged against the dominant field failure mode rather than a maximum value in one bench test.

Table 5. Formulation changes create coupled benefits and penalties.

Formulation lever	Potential benefit	Potential penalty	Evidence needed
Higher base-oil viscosity	Higher film thickness and leakage resistance at temperature.	Higher start-up torque, churning, pumping pressure and starvation risk.	Viscosity at operating temperature, bearing temperature, D1092/loop test, component trial.
Stronger/higher-yield network	Retention, seal against ingress, water spray resistance.	Poor replenishment, injector failure, excess friction, water-induced hardening.	Rheology, pumpability, D4049, bearing or system test.
More tackifier/polymer	Adhesion, reduced fling-off, cohesive stringing.	Churning, filter blocking, poor metering, residue accumulation.	Spray-off, apparent viscosity, low-temperature delivery, deposit inspection.
Higher EP/AW additive loading	Lower scuffing or wear in selected boundary tests.	Corrosion, seal interaction, additive competition, deposits or oxidation penalty.	D2596/D2266 plus corrosion, elastomer, oxidation and component testing.
Solid lubricants	Emergency load support and sliding protection.	Settling, abrasive response to contamination, filtration and high-speed penalty.	Dispersion stability, particle size, wear test matched to contact, cleanliness study.
More polar/synthetic base stock	Lubricity, low-temperature or volatility improvement.	Seal, hydrolysis, solvency, compatibility or cost trade-offs.	Fluid compatibility, oxidation, hydrolytic stability, storage and field trial.

10. Test methods and qualification logic

10.1 Tests answer narrow questions

A technical data sheet is often treated as a product scorecard, but most standard tests answer a narrow question under controlled conditions. A technically defensible qualification plan begins with failure modes, then selects tests that reproduce the controlling mechanism as closely as practical. It also records what each method does not establish. Official ASTM scopes repeatedly warn that many grease tests have no demonstrated direct correlation with service performance [1,2,11-24].

Table 6. Core grease test methods and the limits of inference. Always use the current standard revision and laboratory procedure.

Method	Primary question	Useful interpretation	Do not claim
ASTM D217	Cone penetration of lubricating grease; worked and other conditions.	Consistency and change after defined working.	Not pumpability, bearing life, leakage, water resistance, or speed limit.
ASTM D2265	Dropping point over a wide temperature range.	Temperature at which a drop is released under the method.	Not the maximum continuous operating temperature; above 200 C correlation is especially inappropriate.
ASTM D1831	Roll stability.	Directional consistency change after mechanical working.	No precise prediction of field shear stability or bearing life.
ASTM D1092	Apparent viscosity at selected low-to-moderate temperatures.	Flow resistance relevant to centralized-lubrication pressure drop.	Not a complete injector, line, or bearing replenishment simulation.
ASTM D4693	Low-temperature torque in a grease-lubricated wheel bearing.	Starting/running torque under the specified setup.	Not a universal low-temperature limit for all bearings and systems.
ASTM D1264	Water washout from a bearing assembly.	Percentage mass loss at test temperature.	No established direct service correlation; does not measure post-uptake rheology or corrosion.
ASTM D4049	Water spray-off.	Adhesion/resistance to a direct spray.	Does not establish pumping, corrosion, or bearing life.
ASTM D1743	Corrosion-preventive properties in wet tapered roller bearings.	Static wet-bearing rust rating.	Does not reproduce every brine, process chemical, or dynamic duty.
ASTM D6138	Dynamic corrosion under wet conditions (Emcor).	Corrosion in rotating bearings with selected water medium.	Field chemistry and contamination cycles may differ.
ASTM D2266	Four-ball wear-preventive characteristics.	Relative wear scar under specified sliding conditions.	Not an EP weld test and not a direct service-life predictor.
ASTM D2596	Four-ball extreme-pressure properties.	Weld point, load-wear index and related EP response.	No necessary correlation with rolling-bearing, gear or bushing life.

Method	Primary question	Useful interpretation	Do not claim
ASTM D5483	PDSC oxidation induction time.	Relative oxidation resistance under high-pressure oxygen.	No established direct correlation with service life.
ASTM D942	Oxidation stability by oxygen-pressure drop.	Static oxidation tendency under test conditions.	Not suitable as a universal comparison of grease types or dynamic service life.
ASTM D3336 / D3527	Bearing grease life / automotive wheel-bearing life under defined rigs.	Relative life in the specified bearing and duty.	Application limits differ in speed, load, contamination, fill and relubrication.
ASTM D6185	Compatibility of binary grease mixtures.	Changes in dropping point, worked penetration and storage at multiple blend ratios.	Cannot be replaced by a generic thickener-family chart; does not cover every field ratio or all properties.

10.2 Building an application-specific test ladder

A cost-effective qualification program uses a ladder. Level 1 screens identity and basic physical properties. Level 2 tests the dominant environmental and tribological mechanisms. Level 3 tests the delivery system and component. Level 4 conducts a controlled field trial with baseline data and decision limits. Skipping directly from a data sheet to a fleet-wide conversion transfers uncertainty into operating equipment.

1. Define the failure mode and measurable success criteria: wear, corrosion, washout, temperature, energy, leakage, line pressure, injector delivery, or relubrication interval.
2. Screen finished products against base-oil viscosity, consistency, approvals, water tests, corrosion, tribology, low-temperature behavior, and oxidation data relevant to the duty.
3. Test exact new/old grease mixtures if a complete purge cannot be guaranteed, using ASTM D6185 as a minimum framework and adding pumpability or water testing where those properties govern.
4. Run a system or component test that reproduces flow path, bearing fill, speed, load, temperature and contaminant. Instrument pressure, torque, temperature, vibration and grease delivery.
5. Conduct a controlled field trial with matched equipment, documented purge, sampling plan, inspection criteria, and stop limits. Trend results rather than relying on a single post-trial observation.

11. Comparison with other grease families

Grease-family comparisons are useful only as first-pass screening. Every family contains wide formulation variation, and base oil can dominate temperature, speed, and oxidation behavior. The table below summarizes common tendencies rather than specifications. A well-engineered lithium complex, polyurea, aluminum complex, or anhydrous calcium product can outperform a poorly engineered CSC grease in a given application.

Table 7. Qualitative grease-family tendencies. Finished-product performance can reverse any family-level ranking.

Family	Typical strengths	Common constraints	Where it often fits	Qualification emphasis
Calcium sulfonate complex	Wet corrosion, washout/spray resistance, mechanical stability, high dropping point, strong AW/EP potential.	High apparent viscosity or yield stress; water-induced stiffening; high-speed/low-temp performance varies; compatibility uncertain.	Wet, corrosive, high-load industrial and marine service.	Pumpability/replenishment, contaminated rheology, exact-product compatibility, component temperature.
Lithium complex	Broad availability, balanced high-temperature capability, pumpability and additive flexibility.	Water/corrosion performance depends heavily on formulation; lithium supply/cost considerations.	General industrial, automotive and multipurpose service.	Water/corrosion package, oxidation, bearing life, supply consistency.
Polyurea	Oxidation resistance, low oil bleed in many products, long-life electric-motor bearing applications.	Compatibility can be problematic; shear and water behavior vary; manufacturing chemistry is diverse.	Sealed-for-life or extended-life bearings, electric motors.	Noise, high-speed bearing life, compatibility, low-temperature torque.
Aluminum complex	Adhesion, water resistance, smooth texture, food-grade formulations available.	Tack and shear response can increase churning or pumping difficulty; high-temperature stability varies.	Wet processing, food machinery where registered, open surfaces.	Pumpability, water spray-off, mechanical stability, bearing temperature.
Anhydrous calcium	Good water resistance, low-temperature and pumpability can be favorable in selected products.	Upper-temperature capability generally below complex systems; additive and oxidation performance varies.	Mobile equipment, wet moderate-temperature service, centralized systems.	Temperature ceiling, shear stability, corrosion, delivery at ambient extremes.

Selection rule. Choose the chemistry after identifying the dominant failure mechanism. Do not choose CSC merely because it is lithium-free, has a high dropping point, or produces a high four-ball weld number. Choose it when a finished product demonstrates the required delivery, lubrication, water, corrosion, temperature, material-compatibility and life performance in the intended system.

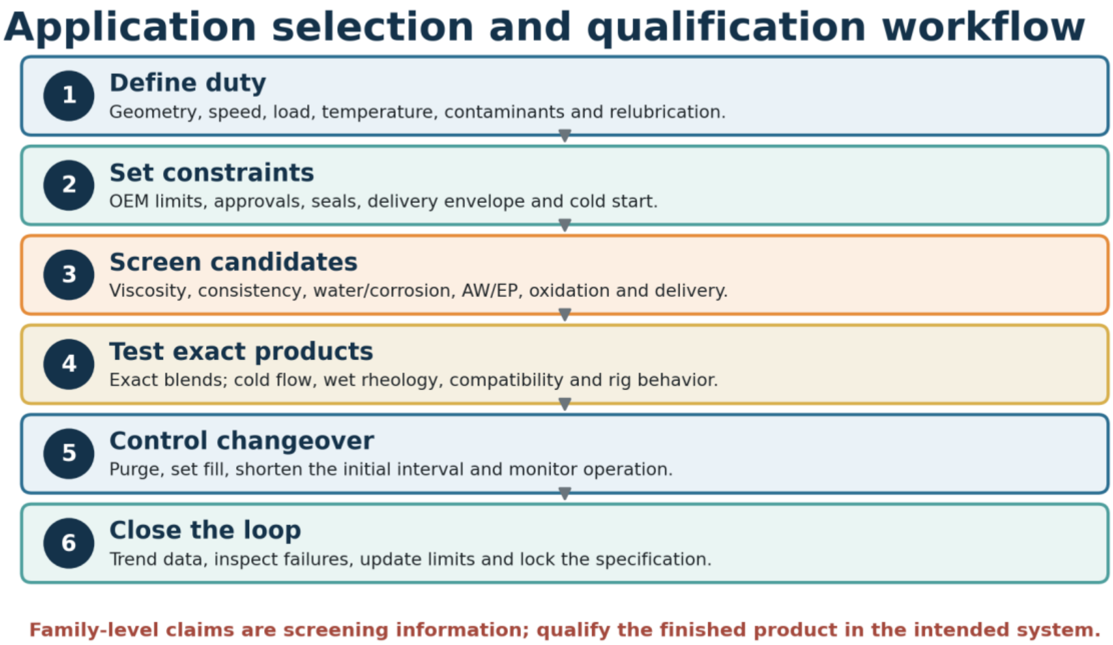

Figure 3. Selection and qualification workflow for a finished CSC grease.

12. Application engineering and operating limits

12.1 Strong application candidates

CSC is often a strong candidate where water, corrosion and high mechanical or boundary load occur together. Examples include roll-neck and mill bearings exposed to cooling water; mining and quarry equipment with water and abrasive ingress; marine deck machinery, docks and wire-rope or open-surface service; pulp and paper wet-end equipment; conveyors and bearings subject to washdown; slow, heavily loaded pins and bushings; pellet mills and process equipment; and certain open gears or couplings. In each case, the grease must still be matched to speed, delivery system, base-oil viscosity, sealing, contamination, and relubrication practice.

Food-processing machinery can also use CSC grease when the finished product is registered and formulated for the required incidental-contact category. The thickener family itself is not an H1 approval. Ingredient restrictions, manufacturing controls, labeling, contamination control, and product registration apply to the complete lubricant [25-27].

12.2 Applications requiring particular caution

High-speed electric-motor and precision bearings require careful evaluation. A CSC grease can have the correct NLGI grade yet generate excessive churning because of high apparent viscosity, tack, or slow channel formation. Noise-sensitive bearings also require filtered product, appropriate particle distribution, and dedicated acoustic testing. Very low ambient temperature, long centralized lines, small-bore tubing, single-line injectors, progressive dividers, and remote grease points require measured delivery at the worst-case temperature. Water-induced stiffening can create a delayed delivery failure even when the fresh grease pumps acceptably.

Small bearings with tight free volume, high oscillation frequency, or low heat dissipation may be intolerant of overfill. Sealed-for-life units require bearing-life evidence rather than relubrication claims. Applications with reactive process chemicals, oxygen service, strong solvents, radiation, very high vacuum, or unusual elastomers need specialist qualification. CSC should not be extrapolated into those duties from general industrial data.

12.3 Engineering the fill and relubrication interval

Grease quantity is a design variable. Excess fill raises drag, temperature, purge pressure and seal stress. Too little grease or an excessively long interval risks starvation and contaminant ingress. The initial fill should follow bearing and housing guidance, adjusted for orientation, speed, purge path and free volume. After conversion to a new grease, stabilized bearing temperature and purge behavior should be established before optimizing the interval.

Relubrication interval should be based on contamination rate, operating temperature, bearing size and speed, seal efficiency, grease life, and the need to purge contaminants. CSC can extend intervals in some wet services because it remains cohesive and protects against corrosion, but an interval extension is an outcome to be demonstrated, not an inherent property. A grease that remains present may still be oxidized, contaminated, hardened, depleted of base oil, or unable to replenish the contact.

Table 8. Application fit and minimum evidence.

Application condition	Why CSC may help	Primary caution	Minimum qualifying evidence
Water spray / washdown	Cohesion, adhesion and sulfonate-based corrosion protection.	Retained water may harden the grease or hold salts.	D1264/D4049, D1743 or D6138, contaminated rheology and pumpability.
Slow, heavily loaded sliding contact	Strong boundary-film and EP/AW potential; high-viscosity base oils available.	Solid contamination and tack can raise abrasion or drag.	Contact-relevant wear/scuffing test, contamination test, field inspection.
High-temperature wet bearing	High dropping point and cohesive structure can resist leakage and water.	Dropping point does not establish bearing life; oxidation and replenishment govern.	Bearing rig/life evidence, oxidation, oil loss, stabilized temperature.
Centralized lubrication	Adhesion and wet protection at remote points.	High yield stress, cold flow and water-induced stiffening may stop delivery.	D1092 or pressure-flow curve, injector/divider loop, worst-case temperature and water state.
High-speed rolling bearing	Possible where base oil and rheology are specifically optimized.	Churning, heat, noise, channeling and replenishment.	Bearing-temperature, torque/noise and life test at actual speed/fill.
Food-processing equipment	Wet/washdown performance can be attractive.	Only the registered finished product qualifies for the required category.	NSF registration/ISO 21469 where required, OEM and material compatibility.

13. Compatibility, changeover, and relubrication control

13.1 Why generic compatibility charts are unreliable

Grease incompatibility can arise from thickener interactions, base-oil immiscibility, additive reaction, acid-base neutralization, polymer collapse, or changes in oil separation. The result may be softening and leakage, hardening and blocked delivery, lower dropping point, oil bleed, granulation, or unstable storage. Because formulations within a thickener family vary, a chart that labels “calcium sulfonate complex versus lithium complex” as compatible or incompatible is only a preliminary risk indicator.

ASTM D6185 addresses this problem by testing exact binary mixtures, typically at 50:50 and off-center ratios such as 10:90 and 90:10, and assessing properties including dropping point, extended worked penetration, and elevated-temperature storage [24]. For a centralized system, those minimum properties should be supplemented with apparent viscosity, injector function and low-temperature flow. For wet service, water-contaminated consistency and corrosion may be more important than dropping point. The field mixture is rarely uniform, so multiple ratios are essential.

13.2 Controlled changeover procedure

1. Identify the installed grease by product name, base oil, thickener, NLGI grade, approvals and service history. Treat an unknown grease as a high-risk mixture.
2. Confirm OEM requirements and component constraints, including seal material, line pressure, bearing speed, fill quantity and food-contact or environmental approvals.
3. Obtain current data and retained samples of both products. Test exact mixtures when full removal cannot be guaranteed.
4. Remove or mechanically clean accessible old grease. Flush lines or reservoirs where practical; do not assume repeated greasing instantly replaces old material in dead zones.
5. Introduce the new grease with a shortened initial relubrication interval and controlled purge. Avoid overfilling while attempting to force a changeover.
6. Trend bearing temperature, vibration, torque or motor current, injector delivery, line pressure, leakage, purge texture, water content and corrosion. Establish stop limits before the trial.
7. After stabilization, optimize fill and interval using evidence. Record the approved product and prohibit uncontrolled top-up with alternatives.

> **Do not “flush” with an incompatible oil.** A flushing oil can dissolve additives, alter seals, leave a low-viscosity pocket, or separate the grease structure. Any flushing method must be approved for the component and followed by a validated refill procedure.

14. Troubleshooting and failure diagnosis

CSC failure analysis should begin with the system, not the grease label. Recover samples from the supply reservoir, line outlet, bearing purge and failed contact where possible. Record sampling location, operating time, temperature, relubrication event, water exposure and visual condition. A single mixed purge sample can conceal whether the problem originated in manufacturing, storage, delivery, contamination or the contact itself.

Table 9. Symptom-based troubleshooting for CSC grease systems.

Observed symptom	Plausible CSC-related mechanisms	System causes to check	Recommended evidence/action
Bearing runs hot after regreasing	Excess fill; high base-oil viscosity; high yield stress/tack; incompatible mixture; water-induced stiffening.	Misalignment, overload, damaged bearing, seal drag, blocked purge.	Verify quantity, purge path, grease identity, temperature trend, motor current, compatibility and bearing condition.
Grease will not reach point	Cold apparent viscosity; stiff batch; absorbed water; hard incompatible mixture; agglomeration.	Undersized line, weak pump, injector fault, blocked divider, air lock, pressure relief.	Measure line pressure and delivered mass at temperature; inspect line sample; run D1092/loop and mixture tests.
Grease softens and leaks	Incompatible mixture; excessive oil separation; process underconversion; solvent contamination.	High temperature, seal damage, overfill, wrong NLGI grade.	Compare fresh/used penetration, FTIR/elemental fingerprint, oil separation, dropping behavior, compatibility.
Grease becomes hard or crusted	Water uptake, oxidation, oil loss, over-thickened batch, reaction with cleaner/process fluid.	Long interval, external heat, poor housing circulation, evaporation.	Water, oxidation, TGA/FTIR, rheology, cross-section sample, process-fluid compatibility.
Rust despite grease presence	Entrained brine, depleted/antagonized inhibitor, free acid, poor coverage, water domains at surface.	Seal ingress, condensation, electrical current, incompatible metal/coating, stagnant housing.	D6138 with actual medium, chloride/pH analysis, surface microscopy, coverage and purge review.
Wear or scuffing despite high four-ball EP	Poor replenishment; wrong base-oil viscosity; additive not active in actual contact; abrasive contamination.	Overload, misalignment, surface damage, insufficient quantity, hard particles.	Contact-specific tribology, particle count/microscopy, film-thickness analysis, delivery verification.
Dark deposits or odor	Oxidation, overheating, additive decomposition, reaction with process chemicals.	Electrical arcing, external contamination, excessive interval, hot spots.	Temperature history, FTIR, acid number/extract, elemental analysis, deposit microscopy.
Lot-to-lot consistency drift	Feedstock change, conversion endpoint variation, moisture, mixing or cooling history.	Sampling and lab reproducibility, storage temperature, packaging shear.	Retained-sample comparison, SPC review, incoming fingerprint, in-process conversion and moisture data.

14.1 Used-grease analytical toolkit

Useful analyses include visual and tactile inspection; worked or unworked penetration where sample volume permits; rheology; water by Karl Fischer or another validated method; infrared spectroscopy; elemental analysis; thermogravimetric or ash content; oxidation indicators; oil separation; microscopy; ferrography or particle analysis; and comparison against fresh and retained production samples. Interpretation must account for mixing with old grease and entrained process material. A change in calcium concentration, for example, may reflect oil loss, addition of another grease, or sampling location rather than a manufacturing defect.

The most valuable result is often a mass-balance or causal chain: the supply grease met release specification; delivery fell below target at low temperature; line pressure rose after water ingress; the bearing received less grease; temperature and vibration increased; and purge samples showed hardened water-containing material. This chain supports corrective action far better than a single high wear-metal result.

15. Food-grade, regulatory, and sustainability considerations

15.1 Food-grade status belongs to the finished product

In the United States, lubricants with possible incidental food contact are formulated under the ingredient and use restrictions of 21 CFR 178.3570 and commonly registered under NSF categories such as H1 [25,26]. ISO 21469 adds hygiene, risk assessment, manufacturing-control and audit expectations for lubricants used in food, cosmetics, pharmaceuticals and related industries [27]. A calcium sulfonate complex thickener is not inherently “food grade.” The finished formulation, manufacturing controls, label, registration status, and intended use determine compliance.

Food-processing qualification must also consider allergen and cross-contamination controls, packaging, color/odor, washdown chemicals, elastomers, incidental-contact limits, and the equipment manufacturer’s instructions. A technically strong nonfood industrial CSC grease cannot be used merely because its base ingredients appear benign. Registration must be current for the exact product and market.

15.2 Environmental and resource claims

CSC is often described as an alternative to lithium-based grease. “Lithium-free” is a compositional fact, not a complete environmental assessment. Environmental performance depends on raw-material sourcing, base-oil type, energy and water used in manufacture, additive hazards, packaging, relubrication consumption, leakage, equipment life, and end-of-life management. Petroleum-derived alkyl sulfonates, mineral oil, calcium compounds, synthetic fluids, and process heat all carry impacts.

A qualified CSC grease may reduce total consumption if it extends relubrication intervals, resists washout, prevents bearing failure, or simplifies inventory. Those benefits can dominate the life-cycle result, but they must be measured. Conversely, an overly stiff product that increases energy use or causes bearing failures is not sustainable. Credible claims should use a defined functional unit, such as lubricant consumed per operating hour or environmental impact per unit of productive equipment life, and should disclose the baseline and boundary conditions.

16. Procurement specification and field-validation checklist

A procurement specification should define the application outcome and controlled product attributes rather than copy a generic "CSC, NLGI 2, high dropping point" description. The supplier should identify the manufacturing site and change-control obligations, while the user should define critical test methods, limits, reporting frequency, retained-sample period, and requalification triggers.

Table 10. Procurement and validation checklist for a CSC grease.

Specification block	Information or test to require	Why it matters
Product identity	Trade name, product code, manufacturing site, grease family, base-oil type, NLGI grade, color/appearance.	Prevents substitution between nominally similar but differently formulated products.
Base oil	Viscosity at 40 C and 100 C, viscosity index, pour point or low-temperature data, chemistry.	Links product to film formation, churning, volatility and pumpability.
Consistency and stability	ASTM D217 worked penetration; extended working or D1831 where relevant; storage stability.	Controls batch consistency and mechanical response.
Thermal properties	ASTM D2265 dropping point plus oxidation and bearing-life evidence appropriate to duty.	Avoids treating dropping point as a service-temperature rating.
Water and corrosion	D1264, D4049, D1743 and/or D6138; contaminated rheology and pumpability for severe wet service.	Separates retention, corrosion protection and post-contamination function.
Tribology	D2266, D2596 and contact-specific test where failure consequence is high.	Confirms boundary performance without relying on a single EP number.
Delivery	D1092 or pressure-flow curve, low-temperature torque where relevant, injector/divider validation.	Ensures the grease reaches the component under worst-case conditions.
Materials	Seal, paint, coating and metal compatibility; filterability/particle limits for precision systems.	Prevents nontribological failure.
Compatibility/changeover	D6185 on exact old/new products and purge procedure.	Controls mixture risk and start-up transients.
Approvals	OEM approval, NSF registration and ISO 21469 certification where applicable, current documentation.	Confirms finished-product suitability and compliance.
Quality system	Certificate of analysis, test frequency, SPC, retained sample, raw-material and process change notification.	Maintains performance across lots and supplier changes.
Field validation	Trial plan, baseline, stop limits, inspection interval, sampling and acceptance criteria.	Converts laboratory evidence into application confidence.

16.1 Recommended acceptance logic

Set a small number of release limits on properties that are both controllable and causally linked to field performance. Use periodic or type-approval testing for expensive life and tribology methods. Require supplier notification and requalification for substantive formulation, raw-material, site or process changes. Define test reproducibility and dispute resolution; a specification tighter than the method precision creates false nonconformance. Where a property is highly application-specific, such as injector refill at minus 20 degrees C with 3 percent water, use a jointly agreed engineering test rather than force an unrelated standard method to answer the wrong question.

17. Conclusions

Calcium sulfonate complex grease is a high-value engineering platform, not a single universal product. Its distinctive performance arises from overbased calcium sulfonate chemistry, controlled conversion of dispersed calcium carbonate to a calcite-rich structure, and interaction with calcium soaps or other complexing species. The same structure that can provide strong water resistance, corrosion protection, mechanical stability and boundary-load performance can also create high apparent viscosity, churning, poor low-temperature delivery, or water-induced stiffening when it is mismatched to the system.

The most reliable selection method follows the chemistry-to-application chain. Specify the required base-oil film behavior and grease transport. Verify conversion and manufacturing consistency. Measure rheology and water response, not only NLGI grade and washout. Interpret dropping point and four-ball results within the limits of their methods. Test exact mixtures during changeover. Use component and field evidence where replenishment, contamination, speed, or failure consequence is critical.

Applied this way, CSC can be an excellent solution for severe wet, corrosive and heavily loaded service and can support longer equipment life and reduced lubricant consumption. Applied as a generic “high-temperature waterproof grease,” it can create avoidable reliability problems. The engineering advantage lies not in the label, but in the disciplined integration of formulation, processing, delivery, contact mechanics, contamination control, and field validation.

> **Final decision criterion.** A CSC grease is suitable when the finished product reaches the contact at the worst expected temperature and contamination state, forms an adequate lubricating film, protects against the actual water or process fluid, remains compatible with system materials and residual grease, and demonstrates acceptable life in the intended operating cycle.

References

[1] ASTM International. ASTM D217, Standard Test Methods for Cone Penetration of Lubricating Grease.

[2] ASTM International. ASTM D2265, Standard Test Method for Dropping Point of Lubricating Grease Over Wide Temperature Range.

[3] Wang, Z.; Xia, Y.; Liu, Z.; Wen, Z. “The rheological and tribological properties of calcium sulfonate complex greases.” Friction, 3 (2015), 28-35. DOI: 10.1007/s40544-014-0063-1.

[4] Zhou, Y.; Bosman, R.; Lugt, P. M. “On the Shear Stability of Dry and Water-Contaminated Calcium Sulfonate Complex Lubricating Greases.” Tribology Transactions, 62(4) (2019), 626-634. DOI: 10.1080/10402004.2019.1588445.

[5] Cyriac, F.; Lugt, P. M.; Bosman, R. “Impact of Water on the Rheology of Lubricating Greases.” Tribology Transactions, 59(4) (2016), 679-689. DOI: 10.1080/10402004.2015.1107929.

[6] Bosman, R.; Lugt, P. M. “The Microstructure of Calcium Sulfonate Complex Lubricating Grease and Its Change in the Presence of Water.” Tribology Transactions, 61(5) (2018), 842-849. DOI: 10.1080/10402004.2018.1431752.

[7] Zheng, H.; et al. “Investigating the effect of overbased sulfonates on calcium sulfonate complex grease: enhancements in physicochemical, rheological, and tribological properties.” RSC Advances, 14 (2024), 32992-33006. DOI: 10.1039/D4RA04307C.

[8] Society of Tribologists and Lubrication Engineers (STLE). “Calcium Sulfonate Complex Greases.” Lubrication Specialist Body of Knowledge technical resource.

[9] European Patent EP2773590A1. “Calcium carbonate based calcium sulfonate complex grease composition and method of manufacture.”

[10] World Intellectual Property Organization. WO2017119999A1. Calcium sulfonate complex grease process and composition disclosures.

[11] ASTM International. ASTM D2596, Standard Test Method for Measurement of Extreme-Pressure Properties of Lubricating Grease (Four-Ball Method).

[12] ASTM International. ASTM D2266, Standard Test Method for Wear Preventive Characteristics of Lubricating Grease (Four-Ball Method).

[13] ASTM International. ASTM D1264, Standard Test Method for Determining the Water Washout Characteristics of Lubricating Greases.

[14] ASTM International. ASTM D4049, Standard Test Method for Determining the Resistance of Lubricating Grease to Water Spray.

[15] ASTM International. ASTM D1743, Standard Test Method for Determining Corrosion Preventive Properties of Lubricating Greases.

[16] ASTM International. ASTM D6138, Standard Test Method for Determination of Corrosion-Preventive Properties of Lubricating Greases Under Dynamic Wet Conditions (Emcor Test).

[17] ASTM International. ASTM D1831, Standard Test Method for Roll Stability of Lubricating Grease.

[18] ASTM International. ASTM D1092, Standard Test Method for Measuring Apparent Viscosity of Lubricating Greases.

[19] ASTM International. ASTM D4693, Standard Test Method for Low-Temperature Torque of Grease-Lubricated Wheel Bearings.

[20] ASTM International. ASTM D5483, Standard Test Method for Oxidation Induction Time of Lubricating Greases by Pressure Differential Scanning Calorimetry.

[21] ASTM International. ASTM D942, Standard Test Method for Oxidation Stability of Lubricating Greases by the Oxygen Pressure Vessel Method.

[22] ASTM International. ASTM D3336, Standard Test Method for Life of Lubricating Greases in Ball Bearings at Elevated Temperatures.

[23] ASTM International. ASTM D3527, Standard Test Method for Life Performance of Automotive Wheel Bearing Grease.

[24] ASTM International. ASTM D6185, Standard Practice for Evaluating Compatibility of Binary Mixtures of Lubricating Greases.

[25] United States Code of Federal Regulations. 21 CFR 178.3570, Lubricants with incidental food contact.

[26] NSF International. Nonfood Compounds Registration Program: lubricant category and formulation evaluation requirements.

[27] International Organization for Standardization. ISO 21469, Safety of machinery - Lubricants with incidental product contact - Hygiene requirements.

About this article

This publication-ready article was developed as a detailed technical expansion of the accompanying Khash video brief. It synthesizes peer-reviewed tribology research, official standard-method scopes, patent disclosures used as process examples, and established grease-engineering principles. Product formulation, regulatory status, and application limits should always be confirmed using current supplier and OEM documentation.