

The Stoichiometry and Synthesis of Potassium Tallowate: A Chemical Engineering Guide to Antibacterial Wood Ash Soap

Introduction to Domestic Surfactant Synthesis and the Saponification Paradigm

The synthesis of surface-active agents, commonly known as soap, represents one of the earliest and most consequential applications of chemical technology and process engineering in human history. The fundamental chemical mechanism—the combination of an alkaline solution with lipid molecules to induce ester hydrolysis and produce an amphiphilic surfactant—has remained structurally and chemically consistent since ancient antiquity. Archaeological evidence, including clay tablets excavated from ancient Mesopotamia dating to approximately 2800 BCE, details the earliest known proto-soaps, which were formulated by combining cassia oil with alkaline water derived from wood ash¹. By the first century CE, historians such as Pliny the Elder documented the production of both hard and soft soaps using tallow and calcined botanical ashes, establishing the metallurgical and chemical utility of oxidized organic matter¹. The etymological root of modern alkali chemistry is derived directly from this ancient reliance on plant ash, with the term "alkali" stemming from the Arabic *al-qalī*, which translates literally to "calcined ashes"¹.

While modern commercial surfactant manufacturing relies almost exclusively on highly refined synthetic detergents (syndets) and standardized, industrially synthesized sodium hydroxide ($NaOH$) or potassium hydroxide (KOH)¹, historical and self-sufficient synthesis dictates a reliance on the domestic extraction of alkali from local biomass and the rendering of animal fats¹. For the pioneers and settlers of the American frontier in the eighteenth and nineteenth centuries, severe geographic isolation necessitated extreme domestic self-sufficiency. Cut off from coastal sodium deposits, these populations engineered a highly functional chemical methodology utilizing the temperate hardwood forests that surrounded them¹. The resulting cycle—leaching soft rainwater through hardwood ash to extract potassium carbonate (K_2CO_3), manipulating chemical equilibrium to convert the lixiviate into potassium hydroxide (KOH) via calcium causticization, and subsequently saponifying rendered animal tallow—stands as a triumph of empirical science and environmental adaptation¹.

In environments requiring strict self-sufficiency, adapting these historical methods utilizing precise stoichiometric calculations yields a highly functional, antibacterial potassium tallowate soap meticulously tailored for kitchen hygiene¹. A functional kitchen soap requires a very

specific biochemical profile: it must possess sufficient detergency to emulsify heavy organic soils, it must resist the oxidative rancidity that plagues poorly formulated domestic soaps, it must maintain physical solubility in varying water temperatures, and it must provide robust antimicrobial efficacy against dangerous foodborne pathogens without relying on synthetic biocides⁵.

This report provides an exhaustive, expert-level analysis of the saponification process utilizing rendered beef tallow and wood ash lye. The analysis is structured to encompass the biochemical characterization of the raw reagents, the thermodynamics and hydrology of causticization and lixiviation, empirical and modern analytical metrology for assessing lye concentration, the reaction kinetics of ester hydrolysis, the complex phase behavior of the resulting potassium carboxylates, the deleterious effects of hard water on the surfactant matrix, and the microbiological efficacy of the final product against common kitchen pathogens. By fusing historical methodologies with modern physicochemical validation, a precise, reproducible guide to synthesizing potassium tallowate is established.

Biochemical Characterization of the Lipid Feedstock: Rendered Beef Tallow

The synthesis of a functional soap requires a complex triglyceride matrix. Tallow is a rendered animal fat obtained primarily from the adipose tissue of cattle and sheep, specifically from suet, which is the dense, hard fat surrounding the kidneys and loins of the animal¹⁰. The rendering process involves the application of sustained thermal energy to raw animal fats to separate the pure lipids from the surrounding connective tissue and proteins, resulting in a highly stable, purified fat matrix that resists putrefaction¹.

Chemically, tallow is composed almost entirely of triglycerides¹⁰. A triglyceride molecule is a triester formed by the esterification of a single, three-carbon glycerol backbone with three long-chain fatty acids (carboxylic acids)¹⁰. The functional behavior of the resulting soap—including its hardness, solubility, lathering profile, and detergency—is fundamentally dictated by the specific fatty acid profile of the tallow, which defines the lengths and saturation levels of the hydrophobic hydrocarbon tails in the resulting surfactant molecules¹⁰.

The fatty acid composition of beef tallow is uniquely suited for heavy-duty cleaning applications due to its dominance by saturated fatty acids (SFAs), specifically palmitic acid and stearic acid, alongside a high concentration of monounsaturated fatty acids (MUFAs), primarily oleic acid¹⁰. Polyunsaturated fatty acids (PUFAs), which are highly susceptible to oxidation, are present only in marginal quantities¹⁰.

Fatty Acid Nomenclature	Carbon Chain Length (Saturation)	Chemical Formula	Average Composition in Beef Tallow (%)
Lauric Acid	C12:0	$C_{12}H_{24}O_2$	0.1 - 1.8

Myristic Acid	C14:0	$C_{14}H_{28}O_2$	3.0 - 4.6
Palmitic Acid	C16:0	$C_{16}H_{32}O_2$	25.0 - 28.0
Palmitoleic Acid	C16:1	$C_{16}H_{30}O_2$	2.6 - 5.0
Stearic Acid	C18:0	$C_{18}H_{36}O_2$	19.0 - 21.2
Oleic Acid	C18:1 (ω -9)	$C_{18}H_{34}O_2$	34.0 - 48.9
Linoleic Acid	C18:2	$C_{18}H_{32}O_2$	2.7 - 3.0
Linolenic Acid	C18:3	$C_{18}H_{30}O_2$	0.5 - 2.0

Table 1: Aggregated compositional analysis of the primary fatty acids esterified within beef tallow triglycerides, demonstrating the dominance of C16 and C18 carbon chains¹⁵. The exceptionally high concentration of palmitic (C16:0) and stearic (C18:0) acids provides significant structural integrity to the fat¹⁰. These long, straight hydrocarbon chains allow the molecules to pack tightly together, resulting in a solid phase at room temperature. Beef tallow possesses a melting point ranging from 42°C to 48°C, with variations extending up to 62°C depending on the specific rendering parameters, the age of the animal, and its dietary history¹⁵. Furthermore, these saturated chains grant the tallow profound oxidative stability, making it highly resistant to thermal degradation and oxidative rancidity during prolonged storage⁸. Conversely, oleic acid (C18:1), which contains a single *cis*-double bond that introduces a "kink" into the hydrocarbon chain, disrupts tight molecular packing. This provides necessary fluidity, yielding a soap that dissolves more readily in water and imparts conditioning properties to the final surfactant matrix¹⁵. Beef tallow is essentially devoid of water, proteins, or carbohydrates, ensuring that the mass measured prior to saponification represents nearly 100% reactive lipids¹⁵.

Defining the Saponification Value and Molecular Weight

For the precise stoichiometric synthesis of soap, the average molecular weight of the triglycerides within the lipid feedstock must be established. Because tallow is a heterogeneous mixture of various triglycerides, an exact molar mass is impossible to define universally; however, it can be mathematically approximated.

The Saponification Value (SV or SAP value) is the critical metric in this calculation. The SV is

defined as the number of milligrams of potassium hydroxide (KOH) required to completely saponify one gram of the specific fat¹⁴. It serves as a direct, inverse measure of the average molecular weight and chain length of the fatty acids present in the sample²⁰. Shorter-chain fatty acids (such as those found in coconut oil) have a lower molecular weight, meaning there are more individual triglyceride molecules—and thus more ester bonds to cleave—per gram of fat¹⁴. Consequently, fats rich in short chains require substantially more KOH to saponify and possess high SAP values¹⁹. Because beef tallow is dominated by relatively long C16 and C18 fatty acids, it exhibits a moderate SAP value. The theoretical SV of a pure triglyceride molecule can be calculated using the following equation:

$$SV = \frac{3 \times 56.1056 \times 1000}{MW_{triglyceride}}$$

Where 3 represents the number of fatty acid residues per triglyceride, 56.1056 is the molar mass of KOH in g/mol, 1000 converts grams to milligrams, and $MW_{triglyceride}$ is the molecular weight of the specific lipid²⁰. Using triolein (a triglyceride containing three oleic acid chains) as a representative model for tallow's unsaturated fraction, the molecular weight is 885.4 g/mol. Applying the formula:

$$SV_{triolein} = \frac{168316.8}{885.4} \approx 190.1 \text{ mg KOH/g}$$

For tristearin (three stearic acid chains), the molecular weight is 891.5 g/mol, yielding an SV of approximately 188.8 mg KOH/g. However, due to the presence of shorter chain fractions like myristic acid (C14:0) and palmitic acid (C16:0), the empirical, accepted SAP value for commercial and domestic beef tallow is universally standardized between 198 and 202 mg KOH per gram of fat²⁰. For the purposes of precise stoichiometric engineering, a median SAP multiplier of 0.200 grams of KOH per gram of tallow is utilized as the absolute baseline for formulation¹⁹.

Arboricultural Chemistry and the Sourcing of Alkaline Salts

While modern saponification relies on the procurement of anhydrous sodium hydroxide or potassium hydroxide pellets synthesized via the chloralkali process, historical methodologies

demand the extraction of alkaline reagents from the inorganic mineral residue left behind after the complete combustion of botanical biomass¹. The chemical efficacy, concentration, and purity of the resulting lye are dictated almost entirely by the species of wood selected for combustion.

The Deciduous Hardwood Imperative

A distinct chemical dichotomy exists between deciduous hardwoods (angiosperms) and softwoods (gymnosperms) regarding their mineral accumulation profiles and subsequent ash yields¹. Deciduous trees draw significantly higher concentrations of primary macronutrients—specifically potassium, calcium, and magnesium—from the soil during their physiological growth cycles to support complex broadleaf metabolic functions¹.

When these hardwoods are subjected to high-temperature combustion in a hearth or kiln, the organic polymers that comprise the wood matrix—predominantly cellulose, hemicellulose, and lignin—undergo rapid thermal oxidation, breaking down into gaseous carbon dioxide, water vapor, and volatile organic compounds¹. What remains is an inorganic mineral residue rich in alkali metal salts¹.

Hardwoods yield a higher total volume of ash by weight compared to softwoods, and crucially, this ash contains a substantially higher mass percentage of potassium carbonate (K_2CO_3)¹.

White oak and hickory are universally recognized as the premier species for primary lye production due to their exceptionally high potassium content, while species such as sugar maple and American beech (*Fagus sylvatica*) are prized for producing a pure, white ash that results in a remarkably clean, lighter-colored soap free of carbonaceous discoloration¹.

Analytical studies of European beech indicate an ash content ranging from 0.2% to 3.5% on a dry basis, which is highly suitable for alkali extraction²⁶.

Conversely, softwoods such as pine, fir, and spruce are actively avoided in the production of high-quality lye¹. Gymnosperms possess a lower overall mineral content and yield a fraction of the potassium found in hardwoods. Furthermore, the higher resin and pitch content endemic to softwoods frequently leaves undesirable, tarry organic residues in the ash that co-extract during lixiviation, discoloring the lye and leaving an odorous, greasy impurity in the final soap¹.

While lye can technically be extracted from softwood ash, modern investigations replicating historical techniques have demonstrated that lye derived purely from softwood sawdust frequently fails to achieve the high alkalinity threshold necessary to fully saponify saturated fats, resulting in a failed, separated emulsion¹.

The Hydrology and Fluid Dynamics of Lixiviation

The physical extraction of the highly soluble potassium salts from the largely insoluble matrix of calcium carbonates, silicates, and metallic oxides present in the ash requires a precisely engineered hydraulic filtration apparatus¹. This system must permit the slow, controlled percolation of an aqueous solvent while completely preventing the fine, silty ash particulate from washing through and contaminating the final alkaline solution¹.

Architecting the Barrel Drip Filtration System

The most ubiquitous and successful configuration for this extraction—formally termed

lixiviation—is the "Barrel Drip Method," often referred to in pioneer literature as an "Ash Hopper"¹. The core of the system is typically a cylindrical wooden barrel (repurposed from flour or wine storage) equipped with a small drainage aperture, approximately one-eighth of an inch in diameter, drilled near the basal edge¹. Highly corrosive alkaline leachates rapidly react with and degrade metals like aluminum; therefore, metal containers and fittings are strictly avoided in favor of wood, glass, or ceramic materials¹.

In more sophisticated domestic setups, the bottom of the barrel is entirely removed, and the wooden cylinder is seated directly onto a specialized architectural feature known as a "lye leaching stone"¹. This is a massive, flat slab of impermeable rock, such as granite or gneiss, into which a circular collection groove has been meticulously carved. The stone is elevated on a slight downward angle, allowing the circular groove to channel the leachate into a carved spout that directs the fluid into a waiting collection vessel¹.

Inside the barrel, a specific stratigraphy is mandatory to create a functional slow-sand-style filter. If the fine ash were simply dumped into the barrel and saturated with water, it would rapidly compact into an impermeable, cement-like sludge, entirely clogging the drainage pathways or allowing murky, ash-laden water to bypass the filter via structural channeling¹. To establish a reliable hydraulic gradient, the filter bed is constructed based on descending porosity:

1. **The Basal Layer (Gravel and Stone):** The lowest level, sitting directly over the drainage holes or the stone groove, consists of clean river stones and coarse gravel. This provides a highly porous foundation that guarantees the free flow of liquid out of the barrel¹.
2. **The Interstitial Layer (Sticks and Driftwood):** Above the stones, a structural matrix of small sticks, twigs, or driftwood is laid down in a crisscross pattern. This layer prevents the finer organic filtration materials above from compressing down into the gravel under the immense weight of the saturated ash¹.
3. **The Primary Filter (Organic Mesh):** A dense, generous layer of clean straw, pine needles, or long grasses—often taking up to six inches or half the total volume of the barrel—is packed tightly over the twigs. This organic mesh serves as the primary physical sieve, capable of catching the microscopic particulate matter of the ash while remaining entirely permeable to the aqueous solvent¹.
4. **The Ash Bed:** Finally, the sifted, cold hardwood ash is shoveled into the remaining volume of the barrel. It is crucial that the ash remains loose and uncompacted, as heavy artificial compaction will halt percolation¹.

Solvent Selection and the Percolation Cycle

The chemistry of the extraction dictates the strict choice of solvent. Practitioners actively seek out "soft water," with rainwater collected in wooden cisterns being the ideal candidate¹.

Rainwater is essentially devoid of the dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions found in "hard" well or river water. If hard water were used as the solvent, the trace metallic and acidic ions would prematurely undergo metathesis reactions with the highly soluble alkaline salts, precipitating them out of solution as insoluble carbonates within the barrel and significantly reducing the chemical yield of the final lye¹.

Water is poured gently and incrementally over the top of the ash bed. Elevated water temperatures are frequently utilized, as increased thermal kinetic energy accelerates the dissolution of the potassium carbonate and draws out a higher total yield of potash from the insoluble matrix¹. The system functions through the slow, relentless force of gravity. The water seeps downward through the microscopic voids, systematically dissolving the water-soluble potassium and sodium salts. This protracted leaching process requires patience, sometimes taking 24 to 48 hours for the fluid front to traverse the barrel, pass through the straw boundary, and begin dripping from the basal apertures¹.

The initial yield, termed the "first run," is typically a dark brown, nearly opaque liquid featuring a distinct oily sheen, a result of dissolved organic compounds, plant lignins, and residual botanical tars co-extracting alongside the alkaline salts¹. A general heuristic indicates that one gallon of sifted hardwood ash yields approximately one quart of weak lye water after a single pass¹.

Thermodynamic Equilibria and the Metathesis of Causticization

A pervasive misconception in modern interpretations of historical soap-making is the chemical identity of the extracted lye. While contemporary commercial lye utilized in cold-process

soap-making is almost exclusively synthesized sodium hydroxide ($NaOH$) or potassium hydroxide (KOH), the raw, unadulterated aqueous extract derived from leaching rainwater through wood ashes is predominantly a solution of potassium carbonate (K_2CO_3), traditionally referred to as "potash"¹.

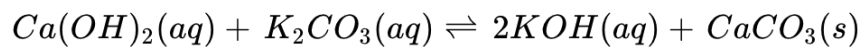
While potassium carbonate is an alkaline salt capable of raising the pH of water, it is a significantly weaker base than a true hydroxide. It lacks the intense chemical causticity required to rapidly and efficiently saponify heavy, saturated animal fats like beef tallow without the application of extreme, prolonged boiling¹. To convert the mildly alkaline potassium carbonate into the highly reactive potassium hydroxide (historically known as "caustic potash"), chemical practitioners employ a sophisticated metathesis process known as causticization¹.

The Stoichiometry of Causticization

Causticization is achieved through the introduction of calcium hydroxide ($Ca(OH)_2$), commonly known as slaked lime, into the aqueous system¹. Slaked lime is produced by heating limestone or seashells (calcium carbonate) to extreme temperatures to drive off carbon

dioxide, producing quicklime (calcium oxide, CaO), which is then hydrated¹.

When a small percentage of this lime is added to the ash barrel prior to leaching, the following reversible double-displacement (metathesis) reaction is initiated within the aqueous solution:

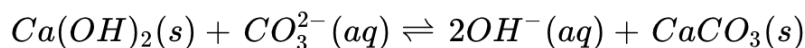


In this aqueous environment, the calcium ions (Ca^{2+}) bond with the carbonate ions (CO_3^{2-}) to form calcium carbonate ($CaCO_3$)¹. Because calcium carbonate is highly insoluble in water (possessing a solubility product constant, $K_{sp} \approx 3.3 \times 10^{-9}$), it immediately precipitates out of the solution as a solid matrix¹. According to Le Chatelier's principle, the continuous removal of the carbonate product via precipitation constantly disrupts the chemical equilibrium, effectively shifting the reaction entirely to the right¹. This leaves the highly soluble and intensely caustic potassium hydroxide (KOH) dissociated in the descending lixiviate¹.

The Thermodynamics of Reaction Spontaneity

The thermodynamic feasibility of this causticization reaction can be rigorously analyzed by assessing the standard Gibbs Free Energy of Formation (ΔG_f°) of the reactants and products. A chemical reaction is considered thermodynamically spontaneous—meaning it will proceed without the continuous input of external energy—if the overall change in standard Gibbs free energy for the reaction (ΔG_{rxn}°) is a negative value³³.

To determine ΔG_{rxn}° , we look at the net ionic equation of the metathesis reaction, as the potassium ions (K^+) act merely as spectator ions in standard state aqueous formation:



The standard Gibbs free energy of formation for the individual components at 298.15 K (25°C) are defined as:

- $Ca(OH)_2(s)$: -898.49 kJ/mol
[cite: 34, 35]
- $CO_3^{2-}(aq)$: -528.1 kJ/mol
[cite: 35]
- $OH^-(aq)$: -157.3 kJ/mol
[cite: 35]
- $CaCO_3(s)$: -1128.79 kJ/mol
[cite: 35]

Using the standard thermodynamic formula:

$$\Delta G_{rxn}^{\circ} = \sum \Delta G_f^{\circ}(\text{products}) - \sum \Delta G_f^{\circ}(\text{reactants})$$

We first sum the free energy of the products:

$$\sum G_f^{\circ}(\text{products}) = [2 \times (-157.3 \text{ kJ/mol}) + (-1128.79 \text{ kJ/mol})]$$

$$\sum G_f^{\circ}(\text{products}) = [-314.6 \text{ kJ/mol} - 1128.79 \text{ kJ/mol}] = -1443.39 \text{ kJ/mol}$$

Next, we sum the free energy of the reactants:

$$\sum G_f^{\circ}(\text{reactants}) = [-898.49 \text{ kJ/mol} + (-528.1 \text{ kJ/mol})] = -1426.59 \text{ kJ/mol}$$

Finally, we calculate the total change in Gibbs free energy:

$$\Delta G_{rxn}^{\circ} = -1443.39 \text{ kJ/mol} - (-1426.59 \text{ kJ/mol})$$

$$\Delta G_{rxn}^{\circ} = -1443.39 + 1426.59 = -16.8 \text{ kJ/mol}$$

The resulting ΔG_{rxn}° of -16.8 kJ/mol confirms definitively that the causticization of potassium carbonate using calcium hydroxide is a thermodynamically spontaneous process at standard room temperature. The process is entirely driven forward by the extreme thermodynamic stability and insolubility of the calcium carbonate precipitate¹.

Historically, this was practically executed by adding approximately 2% to 5% slaked lime by weight to the ash barrel prior to leaching¹. The kinetics of this reaction were ingeniously self-regulating within the barrel system. Calcium hydroxide itself possesses a remarkably low aqueous solubility (approximately 0.19 grams per 100 mL at 20°C)¹. Therefore, the slaked lime remained largely solid within the ash filter bed, slowly dissolving and reacting precisely as the potassium carbonate fluid passed over it. This intrinsic limitation ensured that the final effluent

was overwhelmingly dominated by KOH rather than excess, unreacted calcium, which

would aggressively precipitate the soap and destroy its surfactant properties¹.

Analytical Metrology: Assessing Alkaline Concentration

To successfully initiate saponification, the extracted lye must achieve a highly specific concentration, typically targeting a pH between 13 and 14¹. If the first-run lixiviate is too weak, the triglycerides will not fully react, resulting in a greasy, separated mess of unreacted tallow¹. If the lye is excessively concentrated, the resulting soap becomes an extreme caustic hazard capable of causing chemical burns. Lacking modern digital instrumentation, historical practitioners relied on profound empirical tests leveraging fluid dynamics and protein biochemistry, which can today be verified by rigorous analytical titration.

Empirical Fluid Dynamics: The Egg Buoyancy Test

The physical density of the lye solution was historically calibrated using the "Egg Float Test," a technique governed by Archimedes' principle of buoyancy¹. Archimedes' principle dictates that an object will float if the weight of the fluid it displaces is equal to its own weight. As the concentration of dissolved potassium salts (K_2CO_3 and KOH) increases in the lixiviate, the mass per unit volume (density) of the liquid increases, generating a greater upward buoyant force against a submerged object¹.

A fresh, average large chicken egg possesses a mass of approximately 57 grams, a volume of 51.8 mL, and a specific gravity ranging from 1.08 g/mL to 1.12 g/mL¹. If dropped into pure water (density 1.00 g/mL), the egg rapidly sinks. However, in a properly concentrated lye solution, the high density of the dissolved alkaline salts forces the egg to the surface.

A lye solution suitable for the saponification of tallow must reach a specific gravity of approximately 1.11 g/mL to 1.13 g/mL¹. The visual threshold for success was historically calibrated such that the lye was deemed strong enough when the egg floated with an exposed surface area approximately the size of a US quarter (a 25-cent coin) or roughly half the egg¹. To map this physical indicator to specific chemical concentrations, we examine the density profile of aqueous potassium carbonate solutions at 20°C:

Mass Concentration (wt%)	Molality (mol/kg water)	Molarity (mol/L solution)	Specific Gravity (g/cm ³)
1%	0.073	0.073	1.0072
5%	0.381	0.378	1.0437
10%	0.804	0.789	1.0904

~12.5%	~1.050	~1.020	~1.115
20%	1.809	1.722	1.1898
30%	2.814	2.584	1.2755
50%	7.236	5.573	1.5404

Table 2: Density of aqueous potassium carbonate solutions as a function of concentration at 20°C. Interpolated data reveals that the target specific gravity of 1.11 to 1.13 g/ml corresponds to an active mass concentration of approximately 12% to 15% alkaline salts³⁶.

To mitigate the biological variability of aging eggs—which lose moisture through their shells, expanding their internal air cells and falsely decreasing their overall density—meticulous practitioners pre-calibrated their eggs¹. By using a standardized 5% sodium chloride ($NaCl$) brine solution (yielding a known specific gravity of 1.03), they marked the precise waterline on the shell, creating a custom, calibrated biological hydrometer¹.

Biochemical Causticity: The Keratin Hydrolysis Test

While buoyancy measured the fluid's physical density, the "Feather Test" measured its true chemical causticity. A chicken feather was placed into the heated lye solution; rapid dissolution of the feather indicated that the lye possessed sufficient alkalinity to initiate lipid saponification¹.

This test relies on the mechanism of alkaline hydrolysis. Bird feathers are composed of over 90% beta-keratin, a highly resilient structural protein characterized by long polypeptide chains extensively cross-linked by disulfide covalent bonds ($-S-S-$) derived from the amino acid cysteine¹. These bonds render keratin insoluble in water and highly resistant to biological degradation. However, in the presence of concentrated, hot potassium hydroxide, the extreme abundance of hydroxide ions (OH^-) violently disrupts the keratin matrix. The alkaline environment forces the cleavage of the cystine disulfide bridges, converting them into cysteic acid residues and depolymerizing the macro-structure into soluble short peptides¹. If the feather vanished, the lye was ready.

Modern Quantitative Equivalency: Warder's Titration

For modern chemical engineering processes attempting to precisely replicate historical wood ash soap, the concentration of the mixed hydroxide and carbonate ions can be determined with absolute precision using Warder's titration method³⁸.

Warder's method is a double-indicator acid-base titration utilizing a standardized strong acid titrant, typically hydrochloric acid (HCl)³⁹.

1. **First Endpoint (Phenolphthalein):** The lye sample is titrated in the presence of phenolphthalein. The indicator transitions from pink to colorless at a pH of approximately 8.3. At this exact point, all of the free hydroxide ions (OH^-) have been completely neutralized, and all of the carbonate ions (CO_3^{2-}) have been converted into bicarbonate ions (HCO_3^-)³⁹.
2. **Second Endpoint (Methyl Orange):** Methyl orange indicator is then added to the same flask, and the titration continues. The color transitions from yellow to orange/red at a pH of approximately 4.0, marking the complete neutralization of the newly formed bicarbonate ions into carbonic acid (which dissociates into water and carbon dioxide gas)³⁹.

By recording the precise volume of HCl consumed at each specific endpoint, the chemist can utilize stoichiometric ratios to mathematically separate and calculate the exact molarity of both the caustic KOH and the milder K_2CO_3 present in the lixiviate³⁸. This eliminates the guesswork of the egg test and allows for exact lipid-to-lye calculations.

The Stoichiometry and Kinetics of Saponification

Once the concentration of the potassium hydroxide lye is established, the synthesis of the soap—saponification—commences. Saponification is the irreversible, alkaline hydrolysis of an ester². When the rendered beef tallow (the triglyceride) is subjected to heat and continuous mechanical agitation in the presence of the strong KOH lye, the ester bonds binding the long-chain fatty acids to the glycerol backbone are permanently cleaved².

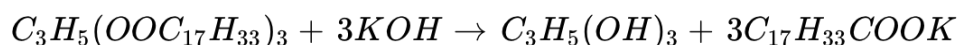
The Nucleophilic Acyl Substitution Mechanism

The chemical reaction proceeds via a well-documented nucleophilic acyl substitution mechanism, advancing through four distinct kinetic stages²:

1. **Nucleophilic Attack:** The hydroxide ion (OH^-) from the aqueous lye acts as a powerful nucleophile, attacking the electrophilic carbonyl carbon of the ester bond on the triglyceride molecule².
2. **Tetrahedral Intermediate Formation:** This nucleophilic attack forces the carbon-oxygen double bond of the carbonyl group to temporarily break, shifting electrons to the oxygen atom and forming a highly unstable, negatively charged tetrahedral intermediate².
3. **Cleavage and Leaving Group Removal:** Seeking stability, the carbon-oxygen double bond rapidly reforms, forcing the expulsion of the alkoxide leaving group (which represents the remaining diacylglycerol complex, and ultimately, the free glycerol backbone)².
4. **Proton Transfer (Deprotonation):** An instantaneous and irreversible acid-base reaction occurs. The highly basic, expelled alkoxide ion strips a proton from the newly formed carboxylic acid. This proton transfer generates the final products: free glycerol (

$C_3H_8O_3$) and the highly stable fatty acid salt—the potassium carboxylate, which is the functional soap molecule².

The idealized stoichiometric equation for the saponification of a representative triglyceride (using triolein, a major component of tallow) with potassium hydroxide is:



(One mole of triglyceride reacts with exactly three moles of potassium hydroxide to yield one mole of glycerol and three moles of potassium oleate soap.)

Precise Stoichiometric Mass Calculations

To prevent a failed product, the exact mass of KOH required to saponify a given mass of tallow must be calculated using the Saponification Value (SV). As established previously, the standardized SV for beef tallow is 200 mg KOH per 1.0 gram of fat²⁰.

For a domestic or pilot-scale production utilizing 1,000 grams (1 kg) of rendered beef tallow:

$$\text{Required Mass of } KOH = 1,000 \text{ g Tallow} \times 0.200 \text{ g } KOH/\text{g Tallow} = 200 \text{ grams}$$

However, because the lye extracted from wood ash is an aqueous solution rather than a dry pellet, the required volume of the lye liquid must be determined using the molarity obtained from Warder's Titration. Assuming the titration determined the lye to have a concentration of 2.0 M (moles per liter) of active KOH :

1. Calculate the moles of KOH required:

$$\text{Moles } KOH = \frac{200 \text{ g}}{56.1056 \text{ g/mol}} \approx 3.565 \text{ moles}$$

2. Calculate the required volume of the 2.0 M lye solution:

$$\text{Volume (L)} = \frac{3.565 \text{ moles}}{2.0 \text{ mol/L}} \approx 1.782 \text{ Liters}$$

Therefore, exactly 1.782 liters of the 2.0 M wood ash lye must be combined with the 1,000 grams of tallow to achieve perfect stoichiometric saponification without leaving hazardous free alkali or greasy unsaponified lipids.

Reaction Kinetics and Activation Energy

The overall kinetics of the saponification reaction follow a second-order rate law, meaning the rate of the reaction is directly proportional to the concentration of both the ester (the triglyceride) and the base (the hydroxide ion)⁴⁴. The rate equation is expressed as:

$$\frac{d[Soap]}{dt} = k[Triglyceride][OH^-]$$

The reaction rate constant (k) is profoundly temperature-dependent, governed by the Arrhenius equation:

$$k = Ae^{-E_a/RT}$$

Where E_a is the activation energy, R is the universal gas constant, and T is the absolute temperature in Kelvin⁴⁵. Experimental physicochemical data indicates that the Arrhenius activation energy for the saponification of fatty acid esters with potassium hydroxide generally falls within the range of 60.3 to 64.0 kJ/mol⁴⁶.

Because the reaction requires significant activation energy (E_a) to overcome the electrostatic repulsion between the hydroxide nucleophile and the electron-dense carbonyl oxygen, thermal energy must be applied to the system (i.e., heating the fat and lye mixture over a hearth)⁴⁷. However, once the ester cleavage initiates, the reaction itself is highly exothermic⁴⁷. The heat of saponification raises the internal temperature of the vessel, which in turn exponentially

increases the reaction rate constant (k), leading to an auto-accelerating kinetic profile⁴⁷.

Continuous mechanical agitation is absolutely critical during the initial phases to maximize the surface area interface between the immiscible hydrophobic lipid phase and the hydrophilic aqueous lye phase. This aggressive mixing forces the emulsion toward a phase state known historically and industrially as "trace," signifying the point at which the emulsion is stable and the reaction is self-sustaining⁵⁰.

Phase Behavior, Krafft Dynamics, and Cation Exchange

A fundamental distinction must be drawn between modern commercial bar soaps and historical wood ash soaps regarding their physical phase behavior. Commercial solid bar soaps

are synthesized using sodium hydroxide ($NaOH$), resulting in sodium carboxylates¹. Inland pioneer processes, utilizing strictly potassium-based wood ash lye, produce potassium carboxylates¹.

Cationic Atomic Radius and The Krafft Boundary

Potassium is a significantly larger atom than sodium, possessing a larger ionic radius¹. This larger ionic size inherently disrupts the crystalline lattice structure when bonded to the fatty acid carboxylate group, rendering potassium soaps substantially more soluble in water and physically weaker than their sodium counterparts¹. Consequently, pure wood ash soap rarely crystallizes into a solid, hard bar. Instead, it forms a gelatinous, highly viscous, amber-colored paste traditionally known as "soft soap"¹.

The physical phase behavior of this surfactant in an aqueous environment is governed by its

Krafft temperature (or Krafft point, T_K). The Krafft point is defined as the critical phase transition temperature below which the surfactant remains as a hydrated, useless crystalline solid, and above which its solubility increases exponentially⁵³. At and above the Krafft point, the surfactant molecules become soluble enough to reach the Critical Micelle Concentration (CMC), allowing them to aggregate into the functional spherical micelles required to encapsulate and lift away dirt and oils⁵³.

Because beef tallow is a composite of different fatty acids, the final soft soap is a heterogeneous mixture of specific potassium salts, each exhibiting distinctly different Krafft dynamics. As the hydrocarbon chain length increases, the Krafft temperature increases due to stronger Van der Waals dispersion forces between the hydrophobic tails, which encourage solid crystallization⁵⁶.

Surfactant Molecule	Derived Fatty Acid	Krafft Temperature (TK)	Physical State at 20°C (Room Temp)
Potassium Laurate	C12:0	~10°C	Fully soluble / Micellar ⁵⁷
Potassium Myristate	C14:0	~25°C	Transitioning / Cloudy ⁵⁷
Potassium Palmitate	C16:0	~45°C	Solid / Crystalline ⁵⁷
Potassium Stearate	C18:0	~55°C	Solid / Crystalline ⁵⁷
Potassium Oleate	C18:1	< 10°C	Fully soluble / Micellar ⁵⁸

Table 3: Krafft points of isolated potassium carboxylates. The data highlights the profound phase differences within the surfactant matrix depending on carbon chain length and saturation⁵⁷.

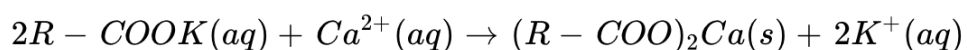
If the soap consisted solely of potassium stearate (derived from tallow's stearic acid), it would remain a solid lump at room temperature and would require washing water heated above 55°C to dissolve and function as a cleanser⁵⁴. However, the high concentration of potassium oleate (derived from tallow's abundant oleic acid) acts as an internal hydrotrope⁵⁸. This creates an eutectic mixture that depresses the overall Krafft point of the entire macroscopic system⁵⁹. The diverse geometries of the carbon chains (particularly the "kinked" oleate chains) disrupt

uniform crystallization, significantly lowering the average T_K and allowing the soft soap paste to solubilize easily in warm kitchen water, readily forming the necessary micelles for robust detergency⁵⁷.

Hard Water Interactions and the Precipitation of Soap Scum

The functionality of potassium tallowate is exceptionally dependent on the mineral content of the water in which it is utilized. In geographical regions characterized by "hard water"—such as Berlin, Germany, which features an average municipal water hardness of approximately 17 °dH (degrees of German hardness, translating to over 250 ppm of calcium carbonate equivalents)—wood ash soap faces a severe chemical impediment⁶⁰.

When the highly soluble potassium carboxylates ($R - COOK$) are introduced to wash water containing heavy concentrations of dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, a rapid, thermodynamically favorable cation exchange occurs⁶³. The divalent calcium ions aggressively displace the monovalent potassium ions on the fatty acid chain, precipitating highly insoluble calcium carboxylates:



This insoluble, waxy precipitate is commonly known in domestic contexts as "soap scum"⁶⁰. This chemical reaction drastically reduces the foaming capacity of the soap, leaves a cloudy, intractable residue on kitchen surfaces and glassware, and physically depletes the active surfactant concentration from the wash basin⁶⁰. Consequently, significantly larger volumes of the soft soap are required to achieve the necessary micellar emulsification of kitchen soils⁶⁰. In such hard-water environments, the subsequent application of a weak acid rinse (such as a 5% acetic acid/vinegar solution) is often required to chemically dissolve the calcium precipitates and restore surface clarity⁶⁰.

Kitchen Hygiene Formulation: Superfatting and Lipid Peroxidation

In modern artisanal and cosmetic soap formulation, it is standard practice to intentionally engineer the recipe with a stoichiometric excess of fat—a technique known as "superfatting"—usually ranging between 5% and 10%⁶⁴. This practice ensures that 100% of the caustic lye is consumed during saponification, leaving a calculated volume of unreacted, free triglycerides suspended throughout the soap matrix to act as emollients for dermal moisturization⁶⁵.

However, for a functional *kitchen hygiene* soap explicitly intended for sanitizing countertops, stainless steel equipment, and dishware, high superfatting is fundamentally counterproductive.

Limitations of Emollients in Cleansing Applications

Excess unsaponified lipids will inevitably leave a greasy, hydrophobic film on washed surfaces, directly interfering with the primary goal of removing organic soils and leaving surfaces sterile and residue-free⁹. Furthermore, exposed, unreacted triglycerides within the soap paste are highly susceptible to lipid peroxidation⁸.

When unsaturated fats (specifically the abundant oleic acid residues in the tallow) are exposed to atmospheric oxygen, ambient heat, and UV light over time, they undergo a free-radical chain reaction⁸. This oxidation cleaves the hydrocarbon chains, degrading them into volatile, short-chain aldehydes and ketones⁸. This process results in oxidative rancidity, imparting highly unpleasant, sharp odors to the soap and significantly reducing its functional shelf life⁸.

Therefore, a kitchen utility soap must be engineered with a very strict, low superfat ratio—ideally between 0% and 2%⁶⁵. This provides a microscopic margin of safety to absolutely prevent the presence of free caustic alkali (which could cause severe skin irritation to the user or strip finishes from kitchen surfaces) while ensuring near-total conversion of the fats into active surfactant molecules, preserving the product's shelf life and maximizing its grease-cutting efficacy⁶⁵. The natural glycerin—a byproduct retained entirely within the soft soap matrix—provides sufficient humectant properties to prevent severe dermal desiccation during frequent handwashing without leaving a lipid residue on dishes¹³.

Antimicrobial Mechanisms and Pathogen Efficacy

Beyond its primary physicochemical function as an emulsifier of fats and particulate soils, properly formulated potassium tallowate exhibits potent, inherent microbiological activity⁵. This makes it highly suitable for stringent kitchen sanitization without necessitating the addition of controversial synthetic antimicrobial agents (such as triclosan or benzalkonium chloride)⁷.

Mechanism of Antimicrobial Action

The antibacterial efficacy of saponified fatty acids is rooted directly in their amphiphilic molecular structure, which allows them to physically interact with and lethally disrupt the lipid membranes of microorganisms⁷⁰. When applied to a contaminated surface, the hydrophobic hydrocarbon tails of the soap molecules intercalate seamlessly into the phospholipid bilayer of the bacterial cell membrane⁷⁰. This aggressive physical insertion alters the membrane's structural fluidity and permeability, leading to the rapid leakage of critical intracellular contents, the collapse of the proton motive force (which is necessary for cellular respiration), and ultimately, complete cell lysis and death⁷⁰.

Furthermore, specific fatty acids target and inhibit essential bacterial enzymatic pathways. For instance, linoleic acid (present in minor but active quantities in tallow) has been demonstrated to act as a potent inhibitor of FabI, an enoyl-acyl carrier protein reductase that is absolutely essential for fatty acid biosynthesis in both Gram-positive and Gram-negative bacteria⁷⁴. This dual-action mechanism—catastrophic structural membrane disruption coupled with targeted enzymatic inhibition—renders the development of bacterial resistance highly unlikely compared to highly specific, single-target synthetic antibiotics⁷³.

Efficacy Against Kitchen Pathogens and Biofilms

The specific potassium carboxylates generated from beef tallow—particularly potassium oleate (C18:1K)—demonstrate exceptional biocidal properties in laboratory settings. In quantitative microbiological assays, potassium oleate has been proven to cause greater than 4-log (

> 99.99%) colony-forming unit (CFU)/mL reductions in the viable populations of dangerous foodborne pathogens, specifically *Staphylococcus aureus* and *Escherichia coli*, within standard washing contact times of under 10 minutes⁵. It also demonstrates a rapid >2-log reduction against highly resilient, spore-forming species like *Clostridium difficile* within one minute of contact⁵.

In the context of domestic kitchen hygiene, cross-contamination via contaminated fomites (cutting boards, knives, countertops, and dish sponges) is a primary vector for severe foodborne illness⁷. Bacteria such as *Staphylococcus aureus* are notorious for colonizing these porous and non-porous surfaces and forming resilient biofilms⁷⁵. Biofilms are complex extracellular polymeric matrices comprised of secreted carbohydrates, proteins, and nucleic acids that physically shield the underlying bacterial colonies from environmental stress and conventional chemical sanitizers⁷⁵.

Clinical research indicates that potassium oleate is significantly more effective at penetrating, dislodging, and removing *S. aureus* biofilms than harsh synthetic detergent standard references, such as sodium lauryl sulfate (SLS) and sodium lauryl ether sulfate (SLES)⁵. In comparative studies, potassium oleate achieved an extraordinary 90.3% biofilm removal rate, significantly outperforming SLS (78.0%) and SLES (74.8%)⁵.

Crucially, while potassium oleate exhibits lethal toxicity toward bacterial cell membranes, extensive cytotoxicity assays demonstrate that it maintains significantly higher viability and lower toxicity toward mammalian cells compared to synthetic detergents⁵. In water-soluble tetrazolium (WST) assays evaluating cell viability, mouse fibroblasts exposed to potassium oleate maintained a 102.8% relative viability compared to controls, whereas fibroblasts exposed to SLS plummeted to 18.1% viability⁵. Similarly, lactate dehydrogenase (LDH) leakage assays (which measure mammalian cell membrane damage) showed potassium oleate caused only 108.9% relative leakage, compared to a massive 523.4% leakage caused by SLS⁵. This ensures that the frequent handwashing and vigorous surface cleaning necessitated by safe kitchen preparation protocols do not result in severe contact dermatitis, epidermal barrier degradation, or cellular damage to the user⁵.

Synthesis and Conclusion

The synthesis of antibacterial kitchen soap from rendered animal tallow and wood ash lye is not a rudimentary domestic chore, but rather a highly sophisticated chemical engineering process that seamlessly bridges historical resourcefulness with exact thermodynamic, stoichiometric, and kinetic principles.

By carefully selecting deciduous hardwoods to yield high-purity potassium carbonate and causticizing the lixivate with calcium hydroxide, the practitioner effectively navigates chemical equilibrium to produce highly reactive potassium hydroxide. Utilizing empirical metrics rooted in fluid dynamics and protein hydrolysis—or modern analytical equivalencies like Warder's double-indicator titration—the alkali is precisely concentrated to perfectly fulfill the exact stoichiometric demands of the heavy tallow triglycerides.

The resulting second-order saponification reaction, driven by applied heat to overcome the activation energy barrier, yields a robust potassium tallowate soft soap. Influenced by the Krafft point depression created by the eutectic mixture of potassium oleate, palmitate, and stearate, the soap remains highly soluble and functionally active at room temperature. When meticulously formulated with a minimal superfat ratio to prevent oxidative rancidity and grease filming, this soap serves as an unparalleled kitchen hygiene agent. It leverages profound amphiphilic membrane disruption and enzymatic inhibition to rapidly eliminate dangerous foodborne pathogens and eradicate resilient biofilms, conclusively proving that classical surfactant chemistry remains profoundly effective and chemically relevant in modern domestic sanitization.

Works cited

1. 76 Historical Pioneer Lye Extraction.pdf
2. Saponification - The Soap-Making Reaction Explained,
<https://sciencenotes.org/saponification-the-soap-making-reaction-explained/>
3. A study on bar soaps and liquid hand wash - PMC - NIH,
<https://pmc.ncbi.nlm.nih.gov/articles/PMC11867263/>
4. (PDF) Exploring Innovations in Soap and Syndet Bar Formulations,
https://www.researchgate.net/publication/400772123_Exploring_Innovations_in_Soap_and_Syndet_Bar_Formulations_A_Comprehensive_Review
5. Fatty Acid Potassium Had Beneficial Bactericidal Effects and ... - PMC,
<https://pmc.ncbi.nlm.nih.gov/articles/PMC6359264/>
6. Soap equation using potash - Chemistry Stack Exchange,
<https://chemistry.stackexchange.com/questions/173090/soap-equation-using-potash>
7. Quantitation of Risk Reduction of E. coli Transmission after Using,
<https://pmc.ncbi.nlm.nih.gov/articles/PMC7598586/>
8. Rancidity in fats and oils: Considerations for analytical testing,
<https://ew-nutrition.com/rancidity-fats-oils-considerations-analytical-testing/>
9. physico-chemical characteristics and antimicrobial - UGSpace,
<https://ugspace.ug.edu.gh/bitstreams/95eeef13-aed2-44ab-ac8f-c9d195739923/download>
10. (PDF) Tallow: Composition, Processing, Functional Properties, and,

- https://www.researchgate.net/publication/399885884_Tallow_Composition_Processing_Functional_Properties_and_Industrial_Applications_-_A_Technical_Review
11. Tallow | Animal Fat, Rendering & Soapmaking | Britannica, <https://www.britannica.com/science/tallow>
 12. Beef tallow: Extraction, physicochemical property, fatty acid, https://japsonline.com/abstract.php?article_id=3447&sts=2
 13. (PDF) Beef tallow: Extraction, physicochemical property, fatty acid, https://www.researchgate.net/publication/354375752_Beef_tallow_Extraction_physicochemical_property_fatty_acid_composition_antioxidant_activity_and_formulation_of_lotion_bars
 14. Definition of SAP value | Soapmaking Forum, <https://www.soapmakingforum.com/threads/definition-of-sap-value.32848/>
 15. Tallow - Wikipedia, <https://en.wikipedia.org/wiki/Tallow>
 16. Synthesis and Characterization of Beef Tallow Biodiesel, <https://pubs.acs.org/enfuem/article/24/8/4476/199169/Synthesis-and-Characterization-of-Beef-Tallow>
 17. Tallow | Tables of composition and nutritional values of feed, <https://www.feedtables.com/content/tallow>
 18. BEEF TALLOW 61789-97-7 wiki - GuideChem, <https://www.guidchem.com/encyclopedia/beef-tallow-dic407348.html>
 19. Soap Making Oil Chart — SAP Values, Fatty Acids & Oil Properties, <https://soapcalc.net/oil-list>
 20. Saponification value - Wikipedia, https://en.wikipedia.org/wiki/Saponification_value
 21. Saponification Value of Fats and Oils as Determined from ¹H-NMR, <https://pmc.ncbi.nlm.nih.gov/articles/PMC9140812/>
 22. Laboratory Saponification Value Determination - Blog, <https://blog.yeswelab.fr/en/cosmetic-plants/laboratory-saponification-index/>
 23. Saponification Value Calculator - GetZenQuery, <https://www.getzenquery.com/tools/saponification-value-calculator/>
 24. Physicochemical Analysis of Soap Produced from Tallow (Animal, https://www.researchgate.net/publication/349325161_Physicochemical_Analysis_of_Soap_Produced_from_Tallow_Animal_Fat_and_Sesamum_Indicum_Seed_Oil_BLENDS
 25. Saponification - Soap Making Process with Ultrasonics, <https://www.hielscher.com/ultrasonic-saponification.htm>
 26. The ash content (%) of European Beech tree components | Download, https://www.researchgate.net/figure/The-ash-content-of-European-Beech-tree-components_fig1_352022665
 27. Thermal behavior and reaction to fire of European beech (Fagus, <https://www.techrxiv.org/doi/10.36227/techrxiv.22495993>
 28. Macronutrient Content in European Beech (Fagus sylvatica L ... - MDPI, <https://www.mdpi.com/1999-4907/13/11/1793>
 29. Method for coproducing calcium carbonate and sodium hydroxide, <https://patents.google.com/patent/US5993772A/en>

30. Toward CO₂-neutral biodiesel production: industrial challenges and, <https://www.oaepublish.com/articles/cf.2025.101>
31. (PDF) Determination of K-sp, Delta G degrees, Delta H degrees, and, https://www.researchgate.net/publication/298157042_Determination_of_K-sp_Delta_G_degrees_Delta_H_degrees_and_Delta_S_degrees_for_the_dissolution_of_calcium_hydroxide_in_water_-_A_general_chemistry_experiment
32. Conceptual Design, Process Simulation, and Techno-Economic, https://www.researchgate.net/publication/412055174_Conceptual_Design_Process_Simulation_and_Techno-Economic_Evaluation_of_a_Modified_Twin-Chamber_Alkaline_Electrolyzer_for_Green_Hydrogen_Production_from_Urea-Rich_Industrial_Wastewater
33. A-Level Chemistry (IGCSE CIE) – Gibbs free energy change - Cognito, <https://cognito.org/courses/alevel/chemistry/cie/notes/S3JwUndsVFE/23.5-gibbs-free-energy-change>
34. Standard Thermodynamic Values, <https://www.drjez.com/uco/ChemTools/Standard%20Thermodynamic%20Values.pdf>
35. Table of Thermodynamic Values, <https://www2.chem.wisc.edu/deptfiles/genchem/netorial/modules/thermodynamics/table.htm>
36. Fig. 2 Preparation of a potassium carbonate (K₂CO₃) solution for, https://www.researchgate.net/figure/Preparation-of-a-potassium-carbonate-K2CO3-solution-for-microplastic-extraction-from_fig2_346032188
37. Densities of Aqueous Solutions of Inorganic Potassium Salts, https://www.engineeringtoolbox.com/density-aqueous-solution-inorganic-potassium-salt-concentration-d_1956.html
38. Warder Titration: Analyze Mixed Alkali Solution - PraxiLabs, <https://praxilabs.com/en/3d-simulations/analysis-mixture-of-sodium-hydroxide-and-sodium-carbonate-by-warder-titration>
39. Warder's method for the titration of carbonates - ResearchGate, https://www.researchgate.net/publication/231191911_Warder's_method_for_the_titration_of_carbonates
40. CO₂ estimation by using titration of Hcl and NaOH gives results, [https://www.researchgate.net/post/CO₂_estimation_by_using_titration_of_Hcl_and_NaOH_gives_results_using_fresh_solutions_itself_How_is_this_possible](https://www.researchgate.net/post/CO2_estimation_by_using_titration_of_Hcl_and_NaOH_gives_results_using_fresh_solutions_itself_How_is_this_possible)
41. Experiment 3 – Determination of Mixed Alkali - pdfcoffee.com, <https://pdfcoffee.com/download/experiment-3-29-pdf-free.html>
42. Titration of Sodium Hydroxide & Carbonate Mixtures - Studylib, <https://studylib.net/doc/8299262/quantitative-determination-of-components-in-solution-cont...>
43. Determination of Activation Energy of Saponification Reaction, <https://www.rroij.com/open-access/determination-of-activation-energy-of-saponification-reactionthrough-ph-analysis-.pdf>
44. Experimental Investigations on Shifting Order Behavior of Ethyl, <https://austinpublishinggroup.com/chemical-engineering/fulltext/ace-v7-id1069.p>

[hp](#)

45. A 32 Saponification Rate Constant of an Ester,
https://www.ipc.kit.edu/download/A_32_engl_180619.pdf
46. (PDF) Determination of the kinetics of biodiesel saponification in,
https://www.researchgate.net/publication/270448427_Determination_of_the_kinetics_of_biodiesel_saponification_in_alcoholic_hydroxide_solutions
47. Why the temperature increase when pour the fatty acid into the KOH,
https://www.researchgate.net/post/Why_the_temperature_increase_when_pour_the_fatty_acid_into_the_KOH-Hydroxypropyl_Methylcellulose_mixing_solution
48. Saponification of Triglycerides and Sodium Hydroxide in the Soap,
<https://scholarlycommons.pacific.edu/purcc/2018/events/95/>
49. A Study of the Kinetics of Aliphatic Ester Saponification.,
<https://preserve.lehigh.edu/system/files/derivatives/coverpage/438721.pdf>
50. How to make natural homemade soap - Basic Autonomy,
<https://basic-autonomy.com/how-to/make-natural-homemade-soap/>
51. Soap Making: Step-by-Step Guide to Make Homemade Soaps,
<https://dokumen.pub/soap-making-step-by-step-guide-to-make-homemade-soaps-advanced-amp-beginner-recipes-included-r-5375172.html>
52. View of Evaluation of Sodium and Potassium Soaps Prepared from,
<https://archive.conscientiabeam.com/index.php/64/article/view/3076/6948>
53. The solubility of sodium and potassium soaps and the ... - Scite.ai,
<https://scite.ai/reports/the-solubility-of-sodium-and-O25WP4>
54. Cloud and Krafft points | Practical Surfactants Science,
<https://www.stevenabbott.co.uk/practical-surfactants/cloud-krafft.php>
55. Krafft temperature, <https://eng.thesaurus.rusnano.com/wiki/article1057>
56. Krafft temperature - Wikipedia, https://en.wikipedia.org/wiki/Krafft_temperature
57. Some Liquid Soap Chemistry - Realize Beauty,
<https://realizebeauty.wordpress.com/2020/04/12/some-liquid-soap-chemistry/>
58. The Solubility of Sodium and Potassium Soaps | www.wenxuecity.com,
<https://www.wenxuecity.com/blog/202309/79226/12639.html>
59. Reexamining the Enhanced Solubility of Sodium ... - ChemRxiv,
<https://chemrxiv.org/doi/pdf/10.26434/chemrxiv-2024-ns2g4>
60. Shampoo Bars for Europe: Hard Water Guide by Country,
<https://naturalanswerproducts.com/best-shampoo-bars-europe-hard-water-guide/>
61. Water quality test results for Berlin - Reddit,
https://www.reddit.com/r/berlin/comments/1rp7z4w/water_quality_test_results_for_berlin/
62. Limescale removal – the guide to limescale-free water,
<https://www.wasserladen.de/en/blogs/news/kalkentfernung-die-anleitung-zu-kalkfreiem-wasser>
63. Survey insights and stats on tap water, bottled water, and filtered water,
<https://tappwater.co/blogs/blog/survey-stats-tap-water-bottled-water-filtered-water-germany>
64. assessment of the quality of soaps produced from blends of,

<https://kubanni.abu.edu.ng/bitstreams/74752b44-8194-4e3f-8857-7d3904e91f2a/download>

65. Why There is No Such Thing As How to Make Soap Without Lye,
<https://www.humblebeeandme.com/why-there-is-no-such-thing-as-how-to-make-soap-without-lye/>
66. ELI5: How does "moisturizing" soap moisturize if the point of soap is,
https://www.reddit.com/r/explainlikeimfive/comments/qgh4hb/eli5_how_does_moisturizing_soap_moisturize_if_the/
67. Lipid degradation during grain storage - UQ eSpace,
https://espace.library.uq.edu.au/view/UQ:6e94099/s4369163_final_thesis.pdf
68. Evolution Analysis of Free Fatty Acids and Aroma-Active ... - PMC,
<https://pmc.ncbi.nlm.nih.gov/articles/PMC8779770/>
69. Skin Cleansing without or with Compromise: Soaps and Syndets,
<https://pmc.ncbi.nlm.nih.gov/articles/PMC8954092/>
70. Fatty Acids as Prebiotics and Their Role in Antibiofilm Activity - MDPI,
<https://www.mdpi.com/2079-6382/15/1/57>
71. Membrane Disruption Properties of Essential Oils—A Double-Edged,
<https://psecommunity.org/wp-content/plugins/wpor/includes/file/2302/LAPSE-2023.5994-1v1.pdf>
72. Exploring Innovations in Soap and Syndet Bar Formulations,
https://auctoresonline.org/uploads/articles/1719586339JPPR-24-RA-191-Galley_Proof-.pdf
73. Mechanisms of the Antimicrobial Action of Fatty Acids: A Review,
https://www.researchgate.net/publication/387201492_Mechanisms_of_the_Antimicrobial_Action_of_Fatty_Acids_A_Review
74. Antibacterial fatty acids: An update of possible mechanisms of action,
<https://pmc.ncbi.nlm.nih.gov/articles/PMC8137538/>
75. Efficacy of Commercial Sanitizers Used in Food Processing ... - MDPI,
<https://www.mdpi.com/2304-8158/8/12/639>
76. (PDF) Antibacterial Activity of Free Fatty Acids, Potassium Soap, and,
https://www.researchgate.net/publication/342563794_Antibacterial_Activity_of_Free_Fatty_Acids_Potassium_Soap_and_Fatty_Acids_Methyl_Esters_from_VCO_Virgin_Coconut_Oil