Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

From Fat to Foam: The Fascinating World of Soap Chemistry and Technology

Hamdy A. Zahran*

Fats and Oils Department, Food Industries and Nutrition Research Institute, National Research Centre, Dokki 12622, Cairo, Egypt

Abstract

In our daily lives, the ubiquitous use of soap extends far beyond mere cleanliness, encompassing diverse applications such as dishwashing, laundry, and personal hygiene, enriching our sensory experience and ensuring a safer, more hygienic living and working environment. Contrary to common perception, the genesis of soap cleansers transcends their role in hygiene, representing a multifaceted innovation with historical roots. Despite its crucial role, soap production stands as a relatively understudied facet of ancient chemical innovation, lacking the archaeological imprints found in materials like ceramics or glass. Unlike inorganic materials, soap leaves no tangible archaeological artefacts to chronicle its evolution. Consequently, our understanding of the chemical technology behind soap relies heavily on historical accounts. The Mesopotamian mud tablets, dating back to the third millennium BCE, provide the most precise evidence of early soap production, offering a glimpse into the chemical ingenuity of our ancestors. While the basic combination of plant ashes and tallow could have facilitated soap production even earlier, concrete proof remains elusive. This article presents a comprehensive review encompassing the historical trajectory, chemical intricacies, technological advancements, and varied applications of soap cleansers. By delving into the annals of history and synthesizing contemporary knowledge, we aim to illuminate the intriguing journey of soap, an everyday marvel often taken for granted.

Keywords: Soap manufacturing, saponification processes, detergents and surfactants, soap types and uses, antiviral soap properties.

1. INTRODUCTION

In the seamless tapestry of our daily lives, soap serves as an unassuming yet integral element, woven into the fabric of cleanliness and hygiene. Beyond its familiar role in personal care and household chores, the chemistry behind soap production unveils a captivating narrative that bridges the realms of science and technology [1]. This exploration delves into the foundational principles governing soap composition, examining the intricate dance between saturated and unsaturated fatty acids, the role of glycerides, and the intricate process of soap synthesis. At its core, soap is a salt formed by the reaction of fatty acids predominantly saturated and unsaturated fatty acids with carbon numbers ranging from C10 to C18 with sodium hydroxide. The source of these fatty acids lies in a blend of natural triglyceride oils. While some manufacturers opt for the direct neutralization of a fatty acid blend, most create soap directly from a blend of oils [2]. This process involves reacting glyceride oils with a strong sodium hydroxide solution, generating soap along with glycerin and copious amounts of heat. The challenge lies in separating soap from the glycerin byproduct, a step that may or may not be deemed necessary. Alternatively, triglyceride oil can be split into fatty acids and glycerin using high temperatures and pressures, allowing for easier separation and subsequent soap formation through neutralization with NaOH solutions [3].

The triglyceride molecules in oils or fats consist of alkyl chains with varying degrees of saturation and unsaturation, resulting in oils with distinct characteristics. While these differences are crucial in edible applications, they play a less prominent role in soap production, where the focus is on the relative proportions of saturated to unsaturated fatty acids and the lengths of the fatty acid chains [4]. The IUPAC defines soap as a fatty acid salt comprising at least eight carbon atoms in the hydrocarbon chain. Soap's utility as a cleanser stems from its surfactant properties, reducing the surface tension between water and oil and facilitating the removal of insoluble contaminants through soap-based micelles [5, 6]. Soap, classified as a detergent and surfactant, offers cleansing properties in weak solutions. However, the expansive category of detergents spans a broader spectrum, with modern detergents, such as alkyl benzene sulfonates, surpassing soap in cleansing capabilities due to enhanced solubility in hard water. Despite this, the historical significance of soap endures, weaving its narrative through the annals of human cleanliness [7-8].

The synergy of different oils in soap production is a deliberate choice, especially in crafting toilet or laundry soaps. Nut oils like coconut oil and palm kernel oil bring long-chain length saturated fatty acids, contributing to soap insolubility at normal temperatures but enhancing lather stability and hardness. Non-nut oils, such as tallows or

*Corresponding author e-mail: hazahran23@gmail.com (Hamdy A. Zahran)
Receive Date: 21 February 2023, Revise Date: 12 December 2023, Accept Date: 12 December 2023
DOI: 10.21608/EJCHEM.2023.195358.7627

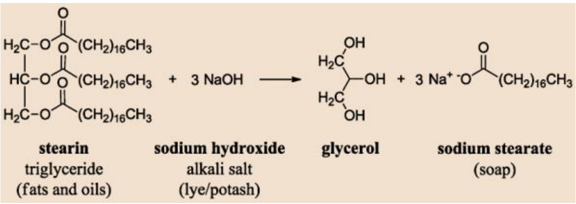
palm oils, provide both long-chain length saturated and unsaturated fatty acids, influencing soap solubility, lather stability, and volume [10]. The intricate interplay between these oils yields soaps with diverse properties, making them a versatile and indispensable aspect of our daily cleansing rituals [3]. As we embark on this exploration of soap chemistry, we peel back the layers of its composition, understanding the alchemy that transforms humble oils into a substance woven into the very fabric of our daily lives. Join us as we unravel the complexities of soap production, where science meets art in the pursuit of cleanliness and hygiene [9].

This introduction sets the stage for a journey through time and innovation, delving into the intricate chemistry, technological nuances, and multifaceted applications that define soap production. From its enigmatic early days to the present, this exploration aims to shed light on the evolution of soap, offering a fresh perspective on a commonplace yet extraordinary element of our daily lives. Join us as we navigate the historical currents and chemical intricacies that underpin the captivating world of soap cleansers.

2. Chemistry of Soap

1.1. Preface

The pivotal method in soap production involves the amalgamation of fats and a soluble base salt, a process known as saponification, illustrated in equation (1) [11]. Alternatively, soap can be derived from the reaction between a fatty acid, such as stearic acid, and an alkali base salt like sodium hydroxide. However, this method faces challenges due to the initial hydrolysis of triglycerides (TGs) to their simple form (fatty acids) and the subsequent removal of glycerol [3], making it impractical for widespread use in manufacturing.



Equation 1. Sodium stearate (soap) resulted from mixing TGs with soluble base salt [12].

- ***Soap Structure and Phase Behavior***

Soap, a substance with ancient origins, has seen its production characterized more by art than science. For instance, the historic soap-boiling process, practiced for centuries, navigated soap mass through various phases with cryptic names like nigre, middle soap, neat soap, kettle wax, and curd [13].

- *Soap Molecular Structure:* Defined as the salt of a fatty acid, soap is the product of the reaction between aqueous caustic soda and fats or oils from natural sources. Functioning as a surfactant molecule, soap possesses a hydrophilic head (the carboxylate group) and a hydrophobic tail (the aliphatic chain). These dual characteristics endow soap with the ability to dissolve both aqueous and organic phases, generate stable foam, and exhibit cleansing properties. The specific properties of a soap depend on the counter-ion(s) and the aliphatic chain(s) present [14, 15]. The distribution of aliphatic chains varies based on the fat or oil source, encompassing chain lengths from C8 to C22 and unsaturation types, such as oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) chains.
- *Soap Phase Structure:*

- *Solid Soap:* In its anhydrous or hydrated state, pure single-chain sodium soap forms a solid crystal structure, exhibiting packed bilayers arranged head-to-head and tail-to-tail. When water is present, a hydrated crystal structure forms, with water located between packed carboxylate heads. X-ray diffraction reveals distinct patterns of long spacing (perpendicular separation between carboxylate heads) and short spacing (lateral separation between parallel aliphatic chains) (Figure 1).

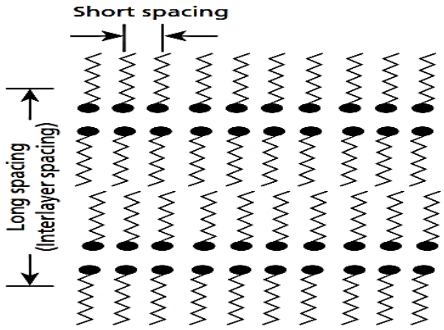


Figure 1: Solid soap crystal showing short and long spacing. Source: [16].

Crystals of pure sodium soaps correlate long spacing with aliphatic chain length, and various short spacing patterns suggest different molecular arrangements, leading to distinct solid soap phases named alpha, beta, delta, and omega [16].

- *Liquid Crystalline Soap:* Liquid crystalline soap phases, categorized as thermotropic and lyotropic, can form when anhydrous soap is heated or mixed with water. These phases exhibit properties of both liquids and solids, maintaining long-range order while losing short-range order. The various types of soap liquid crystals are explored in subsequent sections.
- *Superfatted Soap:* Occasionally, commercial soaps are formulated with excess or free fatty acids, referred to as "superfatted" soaps. Properly formulated superfatted soap bars generate rich, dense lather, a phenomenon attributed to the impact of fatty acids on soap bar structure and phases [17].
- *Transparent and Translucent Soap*: Soap bars are typically opaque due to incident light scattering by heterogeneous domains. This light scattering can be significantly reduced by matching refractive indices or sufficiently reducing the domain size of the dispersed phase. Transparent and translucent soap bars in the commercial realm leverage these phenomena.
- *Cast Transparent Bars:* Known for their transparency, cast transparent bars are produced by dissolving specific soap compositions in hot ethyl alcohol or triethanolamine. The resulting mixture is cast into molds, solidified, and aged for alcohol evaporation, producing transparent bars. These bars, also called

poured or molded bars, are typically a 50% blend of soap and solvent. The manufacturing process, involving demolding when cool, is labor-intensive, contributing to their premium cost [16, 17].

1.2. Triglycerides

Triglycerides are prominent components of lipids, found in various sources such as animal fats and various plant oils. Common oils, including coconut, palm, palm kernel, and olive oils, exhibit diverse fatty acid compositions. While palm oil is derived from the fleshy part of palm fruits, palm kernel oil is obtained from the inner portion. Fats, predominantly present in animals, are semisolid or hard at room temperature, while oils, mainly found in plants but also fish, remain liquid. The composition of fatty substances can vary in terms of chain length and unsaturation level, with solid fats primarily comprising saturated fatty acids and oils predominantly made up of unsaturated fatty acids [18, 19]. Table (1) outlines the fatty acid content of specific lipids found in nature, crucially employed in soap production. Common oils and fats primarily consist of triacylglycerols (TGs), with trace amounts of monoacylglycerols, diacylglycerols, free fatty acids, pigments like chlorophyll and carotenes, and vitamins A, D, E, and K [20]. Simple TGs feature three identical acyl chains, while mixed TGs, more prevalent, consist of various acyl chains.

1.3. Fatty acids

The type of fatty acids in soap production significantly influences the soap's consistency. Sodium salts of lower molecular weight FAs lack soap-like properties, breaking into ions and being water-soluble in molecular solutions. For instance, soap derived from caproic acid (C6:0) exhibits faint soap-like properties with minimal foaming in cold water. As the chain length increases, soap consistency becomes more solid and hard soluble, with lauric acid (C12:0) producing a highly soluble soap, foaming readily in cold solutions, while stearic acid (C18:0) yields a soap slightly soluble in cold water [16]. Historically, fats and oils were sourced locally, minimizing long-distance trade. The primary animal fats produced industrially today are lard (pork) and tallow (beef and lamb), serving various purposes including human consumption, animal feed, and as raw materials in the oleo-chemical industry, primarily used for soap and surfactant compound production [18]. Animal fats were traditionally obtained through rendering, a relatively simple process involving the boiling of fatty animal tissue. Animal fats are easily procured due to the bursting of cell walls and membranes in animal tissue after cooking, causing intercellular fat expansion [21]. In comparison, lipid extraction from plant seeds was also relatively straightforward. In Egypt during the third century BCE, castor oil, flaxseed, and sesame oil were obtained through pressing. However, in first-century BCE Rome, wedge presses, screws, channels, and edge runner mills were employed for oil extraction [22]. The modern refinement of vegetable oils, involving deodorization, bleaching, and neutralization processes, did not occur until the nineteenth century CE [23]. The origin of oils and fats used in soap-making, whether from animal or plant sources, impacts the soap's quality. As shown in Table 1, different plant and animal sources contain varying amounts of several fatty acids, influencing the final consistency and solubility of the produced soap.

Table 1. Fatty acid distribution of common oils and fats are using in soap-making

Fat or oil	FAs distribution (%)										References
	Caprylic (C8:0)	Capric (C10:0)	Lauric (C12:0)	Myristic (C14:0)	Palmitic (C16:0)	Palmitoleic (C16:1)	Stearic (C18:0)	Oleic (C18:1)	Linoleic (C18:2)	Others[a]	
Beef tallow	trace	trace	trace	1.0-5.0	20.0-30.0	7.0-13.0	5.0-10.0	35.0-50.0	0.0-3.0	1.0-3.0	[24]
Lard	trace	0.1-0.5	0.1-0.5	1.5-2.0	23.0-28.0	1.5-3.5	11.0-24.0	29.0-45.0	8.0-12.0	1.0-2.0	[25]
Poultry fat	trace	trace	trace	1.0-2.0	20.0-30.0	3.0-7.5	3.0-7.0	35.0-45.0	15.0-23.0	1.0-2.0	[26]
Coconut oil	4.0-10.0	5.0-9.0	40.0-55.0	10.0-20.0	7.0-11.0	trace	0.5-3.0	5.0-10.0	0.0-3.0	0.0-2.0	[27]
Olive oil	trace	trace	trace	trace	5.0-15.0	trace	0.5-5.0	55.0-83.0	3.0-20.0	0.0-4.0	[28]
Palm oil	trace	trace	trace	trace	30.0-50.0	trace	3.0-10.0	25.0-45.0	3.0-15.0	0.0-5.0	[29]
Palm kernel oil	2.0-8.0	2.0-8.0	35.0-55.0	10.0-25.0	6.0-13.0	trace	1.0-5.0	10.0-20.0	1.0-5.0	0.0-1.0	[30]
Palm stearin	trace	trace	0.1-0.5	1.0-2.0	48.0-74.0	trace	3.5-6.0	15.5-36.0	3.0-10.0	0.0-1.0	[31]
Palm olein	trace	trace	0.1-0.5	0.5-1.5	38.0-43.0	trace	3.5-5.0	40.0-46.0	10.0-13.5	0.0-1.0	[32]

[a] Just FAs that may surpass 1% are recorded (the fatty acid is recorded first, followed by the commonplace rate in fatty sources.

1.4. Alkali Source in Soap-Making

The selection of soluble base salt in soap production significantly influences the characteristics of the resulting soap. Salts like potash (K_2CO_3), soda (Na_2CO_3), and lye (NaOH) find application in soap fabrication. Traditionally, soaps with a firmer consistency are termed hard soaps, while those with a softer consistency are referred to as soft soaps. The nature of the cation in the chosen soluble base salt contributes to the physical attributes of the soap, with sodium (Na^+) salts yielding harder soaps, and potassium (K^+) salts yielding softer ones (George and Raymond, 2016). For example, potassium palmitate [$KCO_2(CH_2)_{14}CH_3$] results in a soft soap, while sodium palmitate [$NaCO_2(CH_2)_{14}CH_3$] produces a hard soap (Friedman, 2016). This distinction arises from the fact that the sodium cation is a stronger acid than the potassium cation and is less polarizable. Additionally, the similar sizes of sodium and oxygen radii contribute to sodium salts having a more favorable lattice energy, resulting in harder soaps. Insoluble soaps, those resistant to water dissolution, can also form from non-alkaline metal ions like lead (Pb^{2+}) or calcium (Ca^{2+}). Historically, alkaline substances such as potash and soda were derived from the incineration of halophytic (high salinity) and alkaline plants, as well as from wood combustion, primarily yielding potash. These plants thrive in high alkali conditions, absorbing basic salts during growth. Coastal marine areas, semi-deserts, and saline and alkaline lakes serve as ideal environments for the cultivation of mineral-rich plants burned for plant ash [33].

The resulting mineral ash, whether potash or soda ash, depends on factors like groundwater and soil conditions, plant species, growth season stage, plant components (leaves or wood), and the incineration process [34]. Inland plants tend to produce potash, while highly alkaline plants favor soda production. Numerous plants in the

Chenopodiaceae family, comprising around 1300 species in 120 genera, have historically been exploited for their high alkali content [34]. Burning these mineral-rich plants in low-oxygen conditions, allowing partial oxidation, yields ash rich in sodium carbonate, with some potassium carbonate and other mineral salts as impurities [35]. Natron, another historical salt source, refers to a mineral not found in plant ash. Instead, sodium sesquicarbonate ($Na_2CO_3.NaHCO_3.2H_2O$), or natron, was mined from evaporate lakes such as Wadi Natrun in Egypt (Gad and El-Zeiny, 2016) (see Figure 2).

Figure 2. Wadi Natrun in Egypt *"Source: Wikipedia"*

2. Soap Making Industry

2.1. Raw Materials

- *Source of Glycerides:* Various glycerides are employed in soap making, with fish oil, tallow, lard, whale oil, and palm oil being common sources for moderately lathering hard lipids. Rapidly lathering hard lipids include oils from kernels, coconut, and palm. Soft oils, contributing to soap's texture, comprise soybean, olive, and cottonseed oils.
- *Rosin:* Derived from plants, rosin, primarily composed of abietic acid ($C_{20}H_{30}O_2$), influences soap color and foaming properties. Colorless rosin variants are utilized in producing light-colored soap, while darker varieties are employed for colored soap, aiding in quicker foam formation and enhancing soap cleansing properties.
- *Caustic Soda:* Available in various forms, including chips, blocks, sticks, and sodium hydroxide solutions, caustic soda plays a crucial role in soap production. It is used in different concentrations, with the potash product also incorporated in manufacturing specialty creams.
- *Sodium Chloride:* Utilized to salt out approximately 12.5 parts per 100 parts of oil during saponification, sodium chloride enhances the soap-making process.
- *Binding Materials:* Tri Sodium Phosphate, Soda ash Sodium, Borax, and Silicate act as binding materials, enhancing soap texture and preventing scum formation in hard water.
- *Fillers:* Starch, talc powder, and pearl ash are employed as fillers, determining the weight of soap without compromising its cleaning properties.
- *Coloring Matter:* Natural and inorganic colors are used in soap production. Methyl violet, safframine, Bismarck brown, chrome green, zinc oxide, ultra-marine, cadmium, vermilion, and eosin are examples. Blending these colors produces a spectrum of hues.
- *Perfumes & Perfume Fixatives:* Natural or synthetic, perfumes and fixatives like lemon grass oil, clove oil, sandalwood oil, lavender oil, cinnamon oil, musk, jasmine, rose, and lylac provide fragrance to soap.

2.2. Formulation of Traditional Soap Cleansing Systems

Over time, soap bar formulation has evolved to incorporate numerous additives. Consumer demands for "green" and "natural" products have led to soap formulations with new materials. The cleansing aspect of soap has taken a back seat to the effects of additives. The industry has witnessed a surge in demand for natural, organic, and sustainable personal care products. However, challenges exist in finding natural equivalents for high-performance synthetic actives.

3. Soap Manufacturing Process

3.1. Saponification

Saponification, derived from the Latin word "saponins" meaning soap, involves splitting esters into alcohols and carboxylic acid salts. Triacylglycerol saponification consists of two steps: hydrolysis of ester linkages producing glycerol and fatty acids, followed by an acid-base reaction with a base (usually NaOH) to form soap and water.

3.2. Indigenous Technology Saponification

A simple cold-process soap-making procedure involves combining NaOH solution with fats and oils, stirring the mixture, adding additives, and air-drying for 24 hours. The resulting soap bars are then assessed for color, texture, lathering, and cleaning power.

3.3. Moulding and Cutting

Melted soap is poured into shaped moulds to set and harden. The soap may be broken out of the mould and cut into desired sizes using wire or cutting machines with various designs.

3.4. Stamping

Special stamps, either electric or manual, are used to imprint trademarks on soap products. Wooden or plastic handmade stamps, stamp boxes, or manual stamping machines are employed.

3.5. Drying

To achieve a defined moisture level, soap is air-dried for hours or up to a month, especially for dry hard soaps. Controlled moisture content ensures the desired appearance after subsequent processing.

3.6. Packaging

Special materials are used to package soaps for the market, usually in cartons. Attractive wrapping with paper or clean polythene enhances sales value, but the associated packaging cost impacts production expenses.

3.7. Soap Manufacturing Processes

Soap production employs either the cold or hot process, with hot processes commonly used for laundry and toilet soaps. Specialty soaps, including translucent variants, are crafted using the cold process. Hot processes yield soaps that are separated from glycerol, an incidental by-product. The hot process is categorized into two main types:

- *Batch Process*

The batch process unfolds in a soap pot constructed with expansive steel plates, as depicted in Figure 3. Steam is introduced, blending with melted fatty substances in precise proportions. Caustic soda is carefully added to initiate the hydrolysis reaction. Boiling ensues until saponification is complete, resulting in a cohesive mass through the conversion of Tri-stearin to Di-stearin. The final product comprises soaps, glycerol, water, excess alkali, and impurities such as sodium carbonate, sodium chloride, and sodium sulfate. Once saponification is finished, steam is removed, and the batch process is concluded, yielding the soap product [36].

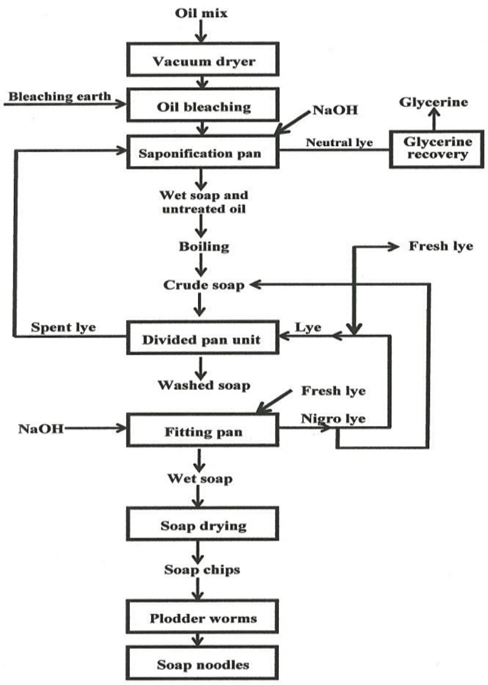


Figure 3. Manufacture of soap by batch process [36].

- *Continuous Process*

In the continuous process, illustrated in Figure 4, fatty materials (fats or oils) and the catalyst, typically zinc oxide, are continuously fed into a hydrolyser or separation tower. Steam loops pass through, heating the charge to around 250ºC at 40 atmospheres of pressure. Continuous hydrolysis occurs in a counter-current manner, leading to the separation of fatty acids and glycerol. Fatty acids proceed to a flash tank or decanter, where excess water is separated. The fatty acids are then directed through a heat exchanger, a vacuum still, and a refining process. The distillate is collected as overhead, and the bottoms are stored for recovery. Neutralization of the distillate with alkali in a continuous neutralizer yields soap. The hot soap is extracted into an agitator tank, containing water, NaCl, and NaOH. Heat and pressure, facilitated by a high-pressure steam exchanger, contribute to drying the soap. The resulting pale mass is aerated, cooled to 65ºC, continuously extruded into soap frames, solidifies as it cools, and is eventually cut into bars. This process is more time-efficient, delivering the final product in a day compared to the batch process, which takes a few days [37, 38].

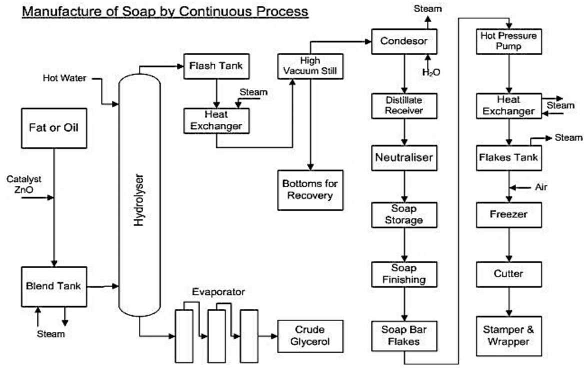


Figure 4. Manufacture of soap by continuous process [38].

4. Different Types of Soaps: Formulation, Functions, and Applications

The formulation of various types of soaps involves a meticulous blend of ingredients to cater to specific cleaning needs. Understanding the distinctive functions and applications of these soaps is crucial for their effective utilization. Toilet soaps, distinguished by Total Fatty Matter (TFM) content, are categorized into grades based on their cleaning efficiency. Laundry soaps, available in liquid or detergent forms, utilize surfactants to interact with dirt and oil, facilitating their removal during the washing process. Guest soaps, often found in hotels, emphasize gentle cleaning with pleasing aromas. Beauty soaps target diverse skin types, offering hydration, acne-fighting properties, or melanin reduction. Dish soaps, tailored for dishware, employ invigorating agents to efficiently eliminate grease stains. Novelty soaps, valued for their decorative appeal, are handcrafted and make charming gifts. Medicated soaps, recommended by specialists, combat skin-related issues and viruses, playing a crucial role in times of pandemics such as Covid-19. Non-toilet soaps excel in removing tough stains, acting as superior cleansers. Handmade soaps, crafted with minimal chemicals, prioritize skin health. Bath soaps, covering a spectrum of cleansing needs, can be used for the entire body. Liquid soaps, versatile in applications, serve purposes ranging from hand hygiene to dishwashing. Exploring the unique formulations, functions, and applications of these diverse soaps provides insights into their roles in maintaining cleanliness across various contexts [39, 40]. The following data in Table (2) shows the different types of soaps and their applications:

5. Soaps vs Detergents

5.1. Chemistry

Soaps, composed of natural ingredients like plant oils (olive, coconut, and palm oils) or fatty acids from tallows, contrast with detergents, which are synthetic derivatives. While soap has limitations in its applications, detergents can be engineered to include various ingredients for diverse cleaning purposes. One of the most versatile and common components in detergents is surfactants, which are surface-active agents [41]. Surfactants play a vital role in cleaning by reducing surface tension and enhancing water's ability to spread evenly. This promotes a more uniform condition that facilitates the removal of dirt and soil. Surfactant molecules may have a positive electric charge, with one end attracted to dirt and grease and the other end to water (Figure 5). This enables detergents to attach to dirt, break it up, and effectively allow water to wash it away [42].

Table (2): Different Types of Soaps and their Applications.

Type of soap	Applications
Toilet Soaps	Toilet soaps, categorized into three grades, exhibit varying TFM levels. Grade 1, with 76% TFM, is a high-grade, processed soap known for abundant foam, diverse colors, and perfumes. Grade 2, featuring 70% TFM, represents trudged soaps with a smooth surface, excelling in washing and cleaning. Grade 3 soaps, containing 60% TFM, are recognized for their firm, smooth texture, often appearing red due to cresylic acid or in other colors, all characterized by superior washing properties.
Laundry Soap	Available as liquid soap or detergents, laundry soaps predominantly contain surfactants, a common ingredient in all laundry detergents. Surfactants, known as surface agents, exhibit a specific property wherein one terminal is attracted to water, and the other to dirt or oil droplets. By binding to dirt in garments, surfactants facilitate its removal by lifting it towards the water during the washing process, effectively eliminating dirt from clothes.
Guest Soaps	Designed for hotel use, guest soaps are petite, fragrant, and gentle on the skin. Often colored and small, they have a limited lifespan but come in various pleasing flavors.
Beauty Soaps	Tailored for different skin types, beauty soaps serve various purposes such as hydration, acne-fighting, or melanin reduction. Available in diverse forms, including liquid gel, these soaps aim to eradicate bacteria while offering aromatic options in multiple colors, additives, prices, and brands.
Dish Soaps	Acknowledged for their efficacy in removing tough stains, dish soaps can be concentrated or light in consistency. Enriched with refreshing agents like lemon and mint, they effectively eliminate oil stains and dirt from plates by attaching to oil and water particles, lifting the dirt into warm water during the washing process.
Novelty Soaps	Primarily used for decorative purposes, novelty soaps captivate with unique shapes, colors, and fragrances. Often handcrafted, they emit pleasant scents and, while not always as effective against microorganisms, prove handy for travel and can be gifted.
Medicated Soaps	Recommended by medical professionals, medicated soaps address skin-related issues and allergies, preventing microbial infections with their antibacterial properties. Particularly relevant in the context of the global Covid-19 pandemic, these soaps, especially antiviral variants, play a role in limiting virus spread and breaking the infection chain.
Non-Toilet Soaps	Characterized as non-beauty soaps, these robust cleansers excel at eliminating heavy dirt, hard oil, and stubborn stains. They are occasionally used as lubricating agents in oils and thickeners, contributing to increased oil viscosity.
Handmade Soaps	Although slightly pricier, handmade soaps are crafted with minimal chemicals, resulting in reduced harm to the skin. Their uniqueness lies in being handmade, showcasing meticulous effort in their creation.
Bath Soaps	An umbrella term covering all skin-use soaps, bath soaps serve to cleanse the entire body. They come in various forms, including gel and solid, catering to different preferences.
Liquid Soaps	Versatile for both hands and body, liquid soaps encompass cleansers for clothing, dishes, and body use. Boasting diverse cleansing agents, they are easily portable and have a prolonged shelf life.
Metallic Soap	Metallic soap, a salt of a monocarboxylic acid and a bivalent or trivalent metal, finds applications in lubricants, driers, thickening agents, waterproofing, flatting, and fungicides. It is typically insoluble in water but soluble in benzene, showcasing its versatility in various industrial applications

5.2. Behaviour in Water

The majority of cleaning products today are detergents, primarily due to how soap interacts with water. Detergents are free-rinsing, leaving no residue, whereas soap requires a clear water rinse after application to avoid leaving a filmy residue (Figure 5). Soaps tend to form foam in water conditions, which not only affects cleanliness but can also damage materials and surfaces. In contrast, detergents can perform effectively in varying water hardness levels, reacting less to the minerals present. Moreover, detergents do not require hot water to function efficiently, unlike soaps, showcasing their versatility in applications ranging from shower gels and shampoos to laundry liquids, stain removers, and hand cleansers [43, 44].

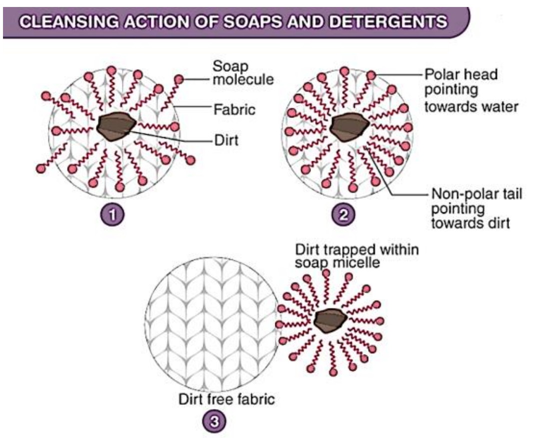


Figure 5. The cleansing action of soaps and detergents [44].

5.3. Soap and Viruses

Soap, derived by combining animal fats or plant oils with an alkali base, comprises molecules with a hydrophobic terminal "head" attracted to water and a hydrophobic tail repelled by water but attracted to lipids (Figure 6). Many bacteria and viruses, including coronaviruses, are enveloped by a protective protein layer with a double-layer structure. When hands are washed with soap, the hydrophobic elements of soap molecules insert themselves into the protein layer, acting like a crowbar to pry the membrane apart and strip it from the virus. The soap molecules then encapsulate the virus fragments, bacteria, and skin-associated dirt, forming small spheres or micelles with the hydrophobic part inside and the hydrophilic part outside [45, 46, 6, 47-49].

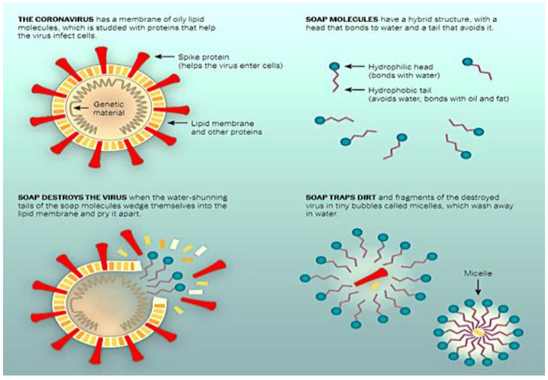


Figure 6. The action of soap against coronaviruses [45].

6. Future directions in soap making and technology

In the foreseeable future, the soap and detergent industry is poised for transformative shifts driven by technological advancements and evolving consumer expectations. Biotechnological innovations, particularly in enzymatic processes and microbial-derived surfactants, offer environmentally friendly alternatives that could reduce energy consumption and waste in soap manufacturing. Nanochemistry applications present opportunities for enhanced formulations, leveraging nanotechnology to improve solubility and enable controlled release of active ingredients. Circular economy principles are expected to play a pivotal role, advocating for soap designs that prioritize recyclability and upcycling, while waterless or minimal water formulations address global concerns about water scarcity. The integration of blockchain technology for supply chain transparency, smart packaging with IoT features, and the development of multi-functional soap products represent avenues for enhanced consumer experiences and sustainability. Encouraging global collaboration for research, consumer education on sustainable practices, and advocacy for green standards will collectively shape the soap and detergent industry toward a more innovative, environmentally conscious, and consumer-centric future.

7. Conclusion

In conclusion, this comprehensive review has delved into the intricate realms of soap and detergent chemistry, manufacturing processes, and their diverse applications. From exploring the historical roots of soap-making to scrutinizing the modern advancements in formulations, additives, and the evolving landscape of the soap industry, the narrative has unfolded the dynamic interplay between tradition and innovation. The chemistry behind soap's cleansing prowess, its juxtaposition with detergents, and the pivotal role it plays in virus deactivation underline the continued relevance and significance of this seemingly humble product. Future trajectories beckon exciting prospects with the integration of biotechnology, nanochemistry, and sustainability practices, promising a transformative shift toward greener, more efficient, and technologically advanced soap and detergent solutions. As the industry navigates toward a future defined by circular economy principles, smart technologies, and heightened environmental awareness, the soap's journey remains a compelling narrative of adaptation, resilience, and ongoing evolution in response to changing societal needs and scientific advancements.

References:

1. Chirani, M. R., Kowsari, E., Teymourian, T., & Ramakrishna, S. (2021). Environmental impact of increased soap consumption during COVID-19 pandemic: Biodegradable soap production and sustainable packaging. *Science of the Total Environment*, *796*, 149013.
2. Prieto Vidal, N., Adeseun Adigun, O., Pham, T. H., Mumtaz, A., Manful, C., Callahan, G., ... & Thomas, R. H. (2018). The effects of cold saponification on the unsaponified fatty acid composition and sensory perception of commercial natural herbal soaps. *Molecules*, *23*(9), 2356.
3. Hall, N., (2016). Implications of Soap Structure for Formulation and User Properties. *In Soap Manufacturing Technology*, AOCS Press, 1-33
4. Baena, A., Orjuela, A., Rakshit, S. K., & Clark, J. H. (2022). Enzymatic hydrolysis of waste fats, oils and greases (FOGs): Status, prospective, and process intensification alternatives. *Chemical Engineering and Processing-Process Intensification*, *175*, 108930.
5. Wickham, P., (2010). Scrapbooks, soap dishes and screen dreams: ephemera, everyday life and cinema history. *New Review of Film and Television Studies*, 8(3), 315-330.
6. Schmidt, C.W., (2020). Lack of Handwashing Access: A Widespread Deficiency in the Age of COVID-19. *Environmental Health Perspectives*, 128(6), 064002.
7. IUPAC (2014). Compendium of Chemical Technology Gold Book; *International Union of Pure and Applied Chemistry*; Version 2.3.3, 2014.
8. Smulders, E.; Rybinski, W. and Nordskog, A., (2011). Laundry Detergents, 1. Ullmann's *Encyclopedia of Industrial Chemistry*, Vol. 20; Wiley-VCH, 355-391.
9. Dunn, K. M. (2010). *Scientific soapmaking: The chemistry of the cold process*. Clavicula press.
10. Kuntom, A., & Kifli, H. (1998). Properties of soaps derived from distilled palm stearin and palm kernel fatty acids. *Journal of Surfactants and Detergents*, *1*(3), 329-334.
11. Preston, W.C., (1925). The modern soap industry. *Journal of Chemical Education*, 2(11), 1035-1044.

12. Konkol, K.L. and Rasmussen, S.C., (2015). An ancient cleanser: Soap production and use in antiquity. *In Chemical Technology in Antiquity*, American Chemical Society, 245-266.
13. Tandon, P.; R. Neubert; and S. Wartewig, (2000). Thermotropic Phase Behavior of Sodium Oleate as Studied by FT-Raman Spectroscopy and X-ray Diffraction, *Journal of Molecules Structure*, 526, 49–57.
14. Murahata, R.I. M.P. Aronson; P.T. Sharko; and A.P., (1997). Greene. Cleansing Bars for Face and Body: *In Search of Mildness, in Surfactants in Cosmetics*, edited by M.M. Rieger, and L.D. Rhein, Marcel Dekker, Inc., New York, 307–330.
15. Piso, Z. and C.A. Winder, (1990). Soap, Syndet, and Soap/Syndet Bar Formulations, in *Soap Technology* for the s, edited by L. Spitz, AOCS Press, Urbana, Illinois, 209–229.
16. Hill, M. and Moaddel, T., (2016). Soap Structure and Phase Behavior. *In Soap Manufacturing Technology*, AOCS Press, 35-54.
17. Bartolo, R.G. and M.L Lynch, (1997). Soap, in *Kirk-Othmer Encyclopedia of Chemical Technology*, edited by Jacqueline I. Kroschwitz and Mary Howe-Grant, John Wiley & Sons, 22, 297–326.
18. Gunstone, F. D. (1999). *Fatty Acid and Lipid Chemistry*; Aspen Publishers: Gaithersburg, MD, 61-86.
19. Scrimgeour, C. M.; Harwood, J. L. (2007). Fatty Acid and Lipid Structure. *The Lipid Handbook*; Gunstone, F. D., Harwood, J. L., Dijkstra, A. J., Eds.; CRC Press: Boca Raton, 1-16.
20. Gunstone, F. D. and Harwood, J. L., (2007). Occurrence and Characterization of Oils and Fats. *The Lipid Handbook*; Gunstone, F. D., Harwood, J. L., Dijkstra, A. J., Eds.; CRC Press: Boca Raton, 37-141.
21. Dijkstra, A. J.; Segers, J. C. (2007). Production and Refining of Oils and Fats. *The Lipid Handbook*; Gunstone, F. D., Harwood, J. L., Dijkstra, A. J., Eds.; CRC Press: Boca Raton, 143-262.
22. Blank, H. B. (1942). Chronological list of important dates in the history of fats and waxes. *Oil & Soap*, 19, 110-113.
23. Ma, Y., Shi, L., Liu, Y. and Lu, Q., (2017). Effects of neutralization, decoloration, and deodorization on polycyclic aromatic hydrocarbons during laboratory-scale oil refining process. *Journal of Chemistry*, 1-9.
24. Basiron, Y. and Shahidi, F., (2005). Bailey's industrial oil and fat products. *Edible Oil and Fat Products: Edible Oils*, 333-429.
25. Pavlisova, J., Bardova, K., Stankova, B., Tvrzicka, E., Kopecky, J. and Rossmeisl, M., (2016). Corn oil versus lard: metabolic effects of omega-3 fatty acids in mice fed obesogenic diets with different fatty acid composition. *Biochimie*, 124, 150-162.
26. Benzertiha, A., Kierończyk, B., Rawski, M., Kołodziejski, P., Bryszak, M. and Józefiak, D., (2019). Insect oil as an alternative to palm oil and poultry fat in broiler chicken nutrition. *Animals*, 9(3), 116.
27. Caballero, B., Finglas, P. and Toldrá, F., (2015). *Encyclopedia of food and health*. Academic Press.
28. Orsavova, J., Misurcova, L., Ambrozova, J.V., Vicha, R. and Mlcek, J., (2015). Fatty acids composition of vegetable oils and its contribution to dietary energy intake and dependence of cardiovascular mortality on dietary intake of fatty acids. *International Journal of Molecular Sciences*, 16(6), 12871-12890.
29. Winkler-Moser, J.K. and Mehta, B.M., (2015). Chemical composition of fat and oil products. *Handbook of Food Chemistry*; Cheung, PCK, Mehta, BM, Eds, 365-402.
30. Tambun, R., Ferani, D.G., Afrina, A., Tambun, J.A.A. and Tarigan, I.A.A., (2019). Fatty Acid Direct Production from Palm Kernel Oil. In IOP Conference Series: *Materials Science and Engineering*, 505(1), 012115, IOP Publishing.
31. Food and Agriculture Organization (2013). CODEX standard for named vegetable oils. *CODEX STAN* 210-1999, 2013 revision
32. Gurr, M.I., Harwood, J.L., Frayn, K.N., Murphy, D.J. and Michell, R.H., (2016). *Lipids: Biochemistry, Biotechnology and Health.* John Wiley & Sons.
33. Warra, A.A., (2013). A report on soap making in Nigeria using indigenous technology and raw materials. *African Journal of Pure and Applied Chemistry*, 7(4), 139-145.
34. Tite, M.S., Shortland, A., Maniatis, Y., Kavoussanaki, D. and Harris, S.A., (2006). The composition of the soda-rich and mixed alkali plant ashes used in the production of glass. *Journal of Archaeological Science*, B (9), 1284-1292.
35. Silva, R.V., De Brito, J., Lynn, C.J. and Dhir, R.K., (2017). Use of municipal solid waste incineration bottom ashes in alkali-activated materials, ceramics and granular applications: A review. *Waste Management*, 68, 207-220.
36. Nwankwojike, B.N., (2012). Design and Development of a Soap Stamping and Tableting Machine for Small Scale Soap Manufacturer. *Nigerian Journal of Technology*, 31(2), 199-205.
37. Sutheimer, S., Caster, J.M. and Smith, S.H., (2015). Green Soap: An Extraction and Saponification of Avocado Oil. *Journal of Chemical Education*, 92(10), 1763-1765.
38. Burleson, G., Butcher, B., Goodwin, B., Sharp, K. and Ruder, B., (2017). Soap-making process improvement: Including social, cultural and resource constraints in the engineering design process. *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, 12(2), 81-102.
39. Ashrafy Habib, S. K., Sorowar, M. S., Karmoker, J., Khatun, M. K., & Al-Reza, S. M. (2016). Study on the physicochemical properties of some

commercial soaps available in Bangladeshi Market. *International Journal of Advanced Research in Chemical Science*, *3*(6), 9-12.

40. Mwanza, C., & Zombe, K. (2020). Comparative evaluation of some physicochemical properties on selected commercially available soaps on the Zambian market. *Open Access Library Journal*, *7*(3), 1-13.
41. Friedman, M. and Wolf, R., (1996). Chemistry of soaps and detergents: various types of commercial products and their ingredients. *Clinics in Dermatology*, 14(1), 7-13.
42. Wolf, R. and Parish, L.C., (2012). Effect of soaps and detergents on epidermal barrier function. *Clinics in Dermatology*, 30(3), 297-300.
43. Bhat, R., Prajna, P.S., Menezez, V.P. and Shetty, P., (2011). Antimicrobial activities of soap and detergents. *Advances Bio resource*, 2(2), 52-62.
44. Panda, H., (2011). *Herbal Soaps & Detergents Handbook*. Niir Project Consultancy Services.
45. Ferris J., (2020). How Washing Hands with Soap Destroys the Coronavirus. https://globalhandwashing.org/how-washing-hands-with-soap-destroys-the-coronavirus/ (Accessed date:26th January, 2021)
46. Rundle, C.W., Presley, C.L., Militello, M., Barber, C., Powell, D.L., Jacob, S.E., Atwater, A.R., Watsky, K.L., Yu, J. and Dunnick, C.A., (2020). Hand hygiene during COVID-19: Recommendations from the American contact dermatitis society. *Journal of the American Academy of Dermatology.*
47. Usman, M., Farooq, M. and Hanna, K., (2020). Environmental side effects of the injudicious use of antimicrobials in the era of COVID-19. *Science of the Total Environment*, 745, 141053.
48. Wollina, U., (2020). Challenges of COVID-19 pandemic for dermatology. *Dermatologic Therapy*, e13430.
49. Ijaz, M. K., Nims, R. W., de Szalay, S., & Rubino, J. R. (2021). Soap, water, and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2): an ancient handwashing strategy for preventing dissemination of a novel virus. *PeerJ*, *9*, e12041.

.