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Benedict Nnachi Alum
Kampala International University, Uganda

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Saponification Process and Soap Chemistry

Benedict Nnachi Alum

Department of Research and Publications, Kampala International University, Uganda

Email:benedict.alum@kiu.ac.ug
ORCID: https://orcid.org/my-orcid?orcid=0009-0005-14855776

ABSTRACT

Saponification is the process of converting fats or oils into glycerol and soap by reacting with alkalis such as potassium or sodium hydroxide. This process is crucial for understanding the chemical makeup of soap and its applications. This review article focuses on the product's historical and modern applications while providing a thorough understanding of the chemistry and saponification process. This article explains the process of saponification, which turns natural fats or oils into soap and glycerol by using an alkali like KOH or NaOH. We explain the steps involved in saponification, which include the hydrolysis of the ester link, the creation of soap molecules, and the impact of the fatty acid chain on the soap's properties. Glycerol, another economically useful byproduct, has multiple uses across many industries and a reputation for sustainability. We also assess the impact of several factors on the soaps, such as temperature, alkali content, mixing techniques, curing times, and additive usage. This paper reviews the valid literature in depth using a thorough historical, scientific, and industrial examination of soap manufacture, including saponification techniques and soap chemistry. Using the bibliometric approach, this review draws attention to the scientific and technological elements of soap manufacture, as well as its wide range of uses in the disciplines of pharmacy, hygiene, and cosmetics.

Keywords: Saponification, Soap chemistry, Alkali, Fatty Acids, Glycerol.

INTRODUCTION

Soap's historical use as a cleaning agent for washing clothes and personal items attests to the saponification process's contribution to its cleaning and emulsifying properties. Saponification, the process that underpins soap production worldwide, involves converting natural fats or oils into alkalis [1]. Beyond the soap applications, research into the chemistry underlying its creation and usage offers a deeper understanding of the fundamental molecular structures governing its efficacy. The interaction of glycerides, typically derived from plants or animals, with a strong base like potassium hydroxide (KOH) or sodium hydroxide (NaOH) theoretically results in saponification [2]. This reaction produces metal salts of fatty acids, or soap molecules, as well as glycerol, also known as glycerin. During the saponification process, a base acting as a nucleophile hydrolyzes the ester linkages in the triglyceride structure [3]. The process entails cleavage of the ester connection that links the fatty acid chain to the glycerol molecule. This releases free fatty acids, which react with the alkali to produce a soap molecule. The type of alkali used—potassium hydroxide for soft soap, and sodium hydroxide for firm soap—determines the soap's characteristics. Potassium hydroxide creates softer soaps that are soluble in water, while sodium hydroxide makes harder soaps that are more suited for cleaning [4]. The different affinities of potassium and sodium ions to the carboxylate anions are what cause this different impact. This is because they determine the structure and character of the soap that is made during the saponification process. The chemical makeup of the fats and oils used also has a significant impact on the soap's composition. Different properties of the three types of fatty acids, such as skin softening, lather creation, and cleaning. Triglyceride molecules' hardness, stability, and texture, which influence consumer preferences and industrial applications, depend on the proportion of these fatty acids integrated into them. Furthermore, saponification is an operation that is dependent on several variables, including temperature, stirring, and reactant purity [5]. Favorable conditions support the achievement of a homogeneous soap quality and the greatest yield of fats or oils in soap. To create the necessary qualities for soap production, certain formulations and environmental conditions must be satisfied. The final product must also pass stringent quality criteria to attest to its efficacy and safety. Apart from its use in bathing and cleaning, the chemistry of soap reveals its versatility in various applications like pharmaceuticals, cosmetics, and industrial uses. Hence, saponification produces glycerin, which is valuable in food, medicine, and cosmetics, underscoring the economic significance of soap production. In conclusion, centuries of scientific invention and discovery have resulted in the process of saponification, which involves chemistry, biology, and industrial technology. Even though soap has a straightforward chemical makeup, scientists have gradually learned more about its molecular structure, which has improved soap's manufacturing and efficiency and led to the discovery of new uses. As a result, soap is now one of the most important cleaning products in the modern world.

Chemical Reactions Saponification

A simple chemical process called saponification turns fats or oils into products like soap and glycerol. This is a brief explanation of its chemical reaction: The term "saponification" describes the procedure of using a strong base, typically potassium hydroxide (KOH) or sodium hydroxide (NaOH), to break the ester bonds in molecules of triglycerides (fats or oils) [6].

Triglyceride+3 NaOH→Glycerol+3 Soap Molecules

or

Triglyceride+3 KOH→Glycerol+3 Soap Molecules [7].

In this reaction:

i. Three fatty acid chains join a glycerol molecule with the structure R-COO to form a triglyceride molecule.
ii. Triglycerides have ester bonds (-COO-) that react with hydroxide ions (OH^-) that are given off by sodium or potassium hydroxide. These ions act as nucleophiles and remove electrons from the nucleus.
iii. Hydrolysis, which breaks the ester bonds and produces three molecules of soap and glycerol, also called glycerin.
iv. The fatty acid salts (RCOONa or K), which are soluble in water and surface-active substances, are often the molecules that makeup soap.

Key points about the chemical reaction of saponification

i. Hydrolysis: The hydroxide ions break the ester bonds, forming glycerol and carboxylate ions, which are salts of fatty acids.
ii. Soap Formation: The products produced, fatty acid salts, or soaps, exhibit both hydrophilic, or water-loving, and hydrophobic, or water-hating, phases. Because of this property, soaps can aid in the emulsification of dirt and oil during washing.
iii. Alkali Influence: Sodium hydroxide forms hard bar soaps, while potassium hydroxide forms soft bar soaps. This is because the physical properties of the soap affect the size and characteristics of the sodium and potassium ions.
iv. Soap Creation Application: The first step in the process of creating soap is saponification, and achieving the ideal soap quality requires adjusting concentrations, stirring speeds, and temperatures. Knowing how saponification works helps explain how soap is made and used to improve global hygiene.

The Role of Alkali in Saponification

Understanding the chemical process of using fats or oils to make glycerol and soap necessitates considering alkali in saponification.

i. **Catalytic Action**: The saponification process uses alkalis such as potassium hydroxide (KOH) and sodium hydroxide (NaOH). These enzymes cause the release of hydroxide ions (OH^-), which accelerate and catalyse the triglyceride molecules' ester bond breakdown [8].
ii. **Triglyceride Hydrolysis**: The hydroxide ions from the alkali saponify the ester bonds (-COO-) connecting the fatty acids to the glycerol in the triglycerides. During this hydrolysis process, fatty acids liberate from glycerol (glycerin) to produce the soap molecules as sodium or potassium salts.
iii. **Types of Soap Produced***:* The qualities of the soap to be made will depend on the alkali used (KOH or NaOH) [9]. Sodium hydroxide (NaOH) is the raw material for hard soap, which is ideal for bar soap and a strong wash. KOH produces a milder, more soluble soap that is appropriate for producing liquid soap with comparatively little cleaning power.

iv. **pH Adjustment**: It also regulates the pH of the soap that is generated, depending on the alkali concentration used [10].

v. **Industrial Application**: To ensure good saponification reactions and high-quality soaps, industrial soap production maintains the concentration and purity of the alkali to high standards [11]. Sodium soaps tend to have an alkaline nature with a pH ranging from 9 to 10, while potassium soaps have a pH of around 8 to 9. We adjust the temperature, speed of stirring, and duration to provide the necessary properties for soap.

vi. **Economic Importance**: The production of glycerol during saponification is highly beneficial not only for soap production, but also for the food, medicine, and cosmetics industries [12]. Its extraction and purification are crucial when determining how economically viable soap production procedures are. Because of this, understanding how alkali functions in saponification is critical when creating soap formulas that meet consumer demands and have the appropriate cleaning capabilities and skin type compatibility.

Types of Fatty Acids and Soap Properties

All else being equal, the types of fatty acids in fats or oils determine the properties of the soap that saponification produces.

i. **Saturated Fatty Acids:** Palmitic acid and stearic acid, two examples of these fatty acids, lack double bonds in their carbon chains due to their saturation with hydrogen atoms [13]. Hard bar soaps with outstanding lathering and cleaning properties are among the soaps produced from oils that have a high S.F.A. content. Although these soaps exhibit stability and good sedimentation qualities, their tendency to dry out the skin necessitates the careful addition of moisturizing ingredients.

ii. **Unsaturated Fatty Acids**: Fatty acids with one or more double bonds between their carbon atoms include oleic and linoleic acids [14]. In general, unsaturated, fatty acid-rich oils produce softer, more moisturizing soaps than saturated oil-based soaps. They may not foam as much as soaps made from saturated fatty acids, but their mildness makes them desirable.

iii. **Chain Length:** This suggests that the length of the carbon chain in fatty acids also influences the soap's characteristics. While short-chain fatty acids like capric and caprylic acid make softer and more soluble soaps, long-chain fatty acids like lauric and myristic acid yield tougher soaps and cleaning agents.

iv. **Combinations**: Different fatty acid percentage proportions make up the majority of natural fats and oils. The proportion of unsaturated to saturated fatty acids in a given oil determines the soap's composition. Lauric acid, a saturated fatty acid present in coconut oil, contributes to the foam and cleanliness of soap, but on its own, it can be drying.

v. **Soap Properties**: The kind and amount of fatty acids in the triglycerides involved in the saponification process determine the physical properties of the soap, including its hardness, litheness, cleansing effectiveness, and emollience [2]. Formulators can blend these oils to maximize their properties and create soaps that cater to specific skin types and preferences.

The varieties of fatty acids in oils and how they affect the qualities of soap enable the soap maker to create oils that address a variety of consumer needs and desires, such as cleansing, moisturising, sensory, and skin concerns.

Glycerin (Glycerol) as a Byproduct

Another crucial substance that is created as a byproduct of the saponification process needed to make soap is glycerol, sometimes known as glycerin.

i. **Formation**: In a process known as saponification, triglycerides, fats, or oils, react with an alkali such as potassium hydroxide or sodium hydroxide to produce glycerin and soap. The component glycerol is produced when ester linkages in the triglyceride molecule break down.

ii. **Chemical Properties:** Glycerol is a pleasant, colourless, odourless trihydroxy sugar alcohol that is not toxic [15]. This substance has a propensity to collect and hold onto water molecules because it is hygroscopic and water-soluble.

iii. **Industrial Uses**: Glycerol finds numerous applications in the sectors listed below. a. Cosmetics and Personal Care: Because it functions as a humectant to maintain skin moisture, it is a common ingredient in skincare products such as lotions, creams, and moisturisers.

b. Pharmaceuticals: Among other formulation uses, glycerol can serve as a solvent, sweetener, or preservative in oral liquids, suspensions, and suppositories [16].

c. Food and Beverage: It is extensively used in candies, baked goods, and beverages, as well as a humectant and sweetening agent in food manufacturing.

d. Industrial Applications: Glycerol is used as a raw material in the production of other chemicals, such as propylene glycol, and as a component of antifreeze mixtures and lubricating solutions in a variety of industries [17].

iv. **Economic Importance**: The extraction and purification of glycerol from the soap-making process partially offsets the cost of the saponification operations. This product finds widespread use across various sectors worldwide.

v. **Sustainability**: Glycerol is more environmentally friendly than its synthetic equivalents because it comes from natural fats and oils, which are renewable supplies [18]. The company's sustainable manufacturing profile is in line with the evolving ideals of its customers, who are becoming more environmentally sensitive.

As a result, glycerol is a useful byproduct of saponification with a broad range of applications in the culinary, pharmaceutical, cosmetic, and other industries. These qualities highlight the material's economic significance and suitability for modern industrial processes, making it indispensable across a range of industries.

Factors Affecting Soap Quality

As will be discussed below, several factors can influence the quality of soap produced via the saponification method.

i. **Ingredients:** The type and amount of fats or oils used will influence the final soap's quality. The amounts of saturated and unsaturated fatty acids in different oils affect soap's overall qualities, such as hardness, lathering power, cleaning effectiveness, and moisturizing effect [19].

ii. **Alkali Concentration:** During the saponification process, the concentration and purity of the alkali—typically potassium or sodium hydroxide—are crucial. The effectiveness, texture, and pH level of the soap are all determined by the mole ratio and accurate measurements of oils, lye, and essential oils [20].

iii. **Temperature:** Because saponification reactions are exothermic, temperature variations might affect them. Temperature conditions are regulated since they promote reaction speeds and aid in preserving the soap's quality. The converse is true for low temperatures, which have a slow rate of saponification. High temperatures are also beneficial in accelerating saponification, although the heat may also affect the texture and colour of the soap.

iv. **Agitation and Mixing:** During the saponification process, proper mixing and stirring are necessary to make sure that all of the ingredients are well combined and improve the alkali's distribution in the fat or oil sample [21]. Proper mixing enhances the homogeneity and stability of the soap by improving the distribution of the constituents, enhancing the soap's homogeneity and stability.

v. **Curing and Ageing:** We allow the soap to age for a few weeks after saponification, which enhances its hardness, mildness, and longevity. Curing removes moisture from the soap, resulting in a firmer, less abrasive feel that enhances lather and extends its useful life [22].

vi. **Fragrances and additions**: Botanicals, essential oils, colourants, and moisturisers are examples of soap additions that can improve the soap's qualities and make it more appealing to consumers. However, we must carefully choose and add additives at the right stage of the process to maintain the soap's stability and effectiveness.

vii. **Quality Control:** We use random checks and various methods of quality assurance and control to uphold the standard and adhere to the established soap specifications. We must evaluate daily sanitation, pH, moisture content, hardness, lather quality, and sensory qualities to satisfy QC requirements and consumer expectations [2].

To create high-quality soaps that provide end users with correct cleaning, skin moisturizing, and feel, soap producers must recognise and regulate these variables. Changing such aspects makes it easier to adjust the technology of soap compositions to meet market demands and consumer preferences.

CONCLUSION

As a result, the crucial chemical step of saponification is what turns fats or oils into glycerol and soap. This technique uses alkalis, such as potassium or sodium hydroxide, to break ester bonds inside triglycerides to produce glycerin and soap. The type of alkali used determines the type of soap formed; potassium hydroxide is used to make gentle soaps for emulsion applications, whereas sodium hydroxide is used to make hard soaps for cleaning. Aside from fatty acid makeup, other factors influencing soap quality include temperature, mixing, curing, and additions. Not only does saponification serve hygienic purposes, but it also facilitates the production of glycerol, a valuable product in various sectors. This makes saponification both environmentally and economically advantageous.

REFERENCES

1. Moshiri,hossien:Saponification, https://chemkraft.ir/en/saponification/, (2023)
2. Prieto Vidal, N., Adeseun Adigun, O., Pham, T.H., Mumtaz, A., Manful, C., Callahan, G., Stewart, P., Keough, D., Thomas, R.H.: The Effects of Cold Saponification on the Unsaponified Fatty Acid Composition and Sensory Perception of Commercial Natural Herbal Soaps. Molecules. 23, 2356 (2018). https://doi.org/10.3390/molecules23092356
3. Ashenhurst, J.: Basic Hydrolysis of Esters - Saponification, https://www.masterorganicchemistry.com/2022/10/27/saponification-of-esters/, (2022)
4. potassium hydroxide vs. sodium hydroxide | Badger & Blade, https://www.badgerandblade.com/forum/threads/potassium-hydroxide-vs-sodium-hydroxide.577049/
5. Chemical reaction engineering, https://www.slideshare.net/slideshow/chemical-reaction-engineering-28330576/28330576
6. Saponification, https://en.wikipedia.org/w/index.php?title=Saponification&oldid=1200003410, (2024)
7. Saponification - Definition,Reactions, Mechanism, Examples, Saponification Value, Uses, FAQs with Videos on Saponification., https://byjus.com/chemistry/saponification/
8. Bashyal, J.: Saponification: Reaction, Mechanism, Values, Examples, Uses, https://scienceinfo.com/saponification-uses-examples-values/
9. What Are the Best Soap-Making Chemicals?, https://camachem.com/fr/blog/post/what-are-the-best-soap-making-chemicals
10. All soaps need lye. But the lye's pH level is 13-14. Would it affect the pH level of the soap?, https://www.quora.com/All-soaps-need-lye-But-the-lyes-pH-level-is-13-14-Would-it-affect-the-pH-level-of-the-soap
11. Selladurai, A., Kathiresapillai, V.: Preparation of Soaps by Using Different Oil and Analyze their Properties.(2019). https://doi.org/10.4172/2329-6836.1000357
12. Sivasankaran, C., Guruviah, K., Jayamuthunagai, J., Bharathiraja, Dr.B., Ramanujam, P.K., Raman, J.: Conversion of Glycerol to Valuable Products. Presented at the October 1 (2019)
13. Saturated Fatty Acid - an overview | ScienceDirect Topics, https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/saturated-fatty-acid
14. Unsaturated acid | chemical compound | Britannica, https://www.britannica.com/science/unsaturated-acid
15. Glycerol | Trihydroxy alcohol, Fatty acid ester, Solvent|Britannica, https://www.britannica.com/science/glycerol
16. Glycerol, https://en.wikipedia.org/w/index.php?title=Glycerol&oldid=1225262118, (2024)
17. The Many Faces of Glycerol Applications Uncovered, https://kumarmetal.com/glycerol-applications/, (2022)
18. Chilakamarry, C.R., Sakinah, A.M.M., Zularisam, A.W., Pandey, A.: Glycerol waste to value added products and its potential applications. Syst Microbiol and Biomanuf. 1, 378–396(2021). https://doi.org/10.1007/s43393-021-00036-w
19. Azme, S.N.K., Yusoff, N.S.I.M., Chin, L.Y., Mohd, Y., Hamid, R.D., Jalil, M.N., Zaki, H.M., Saleh, S.H., Ahmat, N., Manan, M.A.F.A., Yury, N., Hum, N.N.F., Latif, F.A., Zain, Z.M.: Recycling waste cooking oil into soap: Knowledge transfer through community service learning. Cleaner Waste Systems. 4, 100084 (2023). https://doi.org/10.1016/j.clwas.2023.100084
20. Common mistakes when making cold process soap, https://essencetics.com/blogs/interesting/common-mistakes-when-making-cold-process-soap
21. 12: Making Soap - Saponification (Experiment), https://chem.libretexts.org/Ancillary_Materials/Laboratory_Experiments/Wet_Lab_Experiments/General_Chemistry_Labs/Online_Chemistry_Lab_Manual/Chem_9_Experiments/12%3A_Making_Soap_-_Saponification_(Experiment)
22. Cure time... | Soapmaking Forum - Soap & CandleForums, https://www.soapmakingforum.com/threads/cure-time.35831/

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