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ENVIRONMENTALLY ORIENTED OPTIMIZATION OF SYNTHETIC DETERGENT FORMULATIONS

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Abstract Synthetic detergents (SDs) are widely used in households and industry; however, traditional formulations pose a serious threat to the environment due to the poor biodegradability and toxicity of certain components. This article examines principles and practical approaches to environmentally oriented optimization of detergent composition, aimed at reducing the ecological impact while maintaining washing efficiency. Alternative surfactants, phosphate-free builders, and biodegradable additives are analyzed. A life cycle assessment (LCA)-based optimization methodology is proposed.

Keywords: synthetic detergents, green chemistry, biodegradability, surfactants, phosphates, LCA, sustainable formulations

Introduction This study attempts a comprehensive optimization of detergent formulations to improve biodegradability, reduce toxicity, and minimize negative impacts on natural water bodies. The work considers alternative surfactants, biodegradable additives, and methods for evaluating acute toxicity and environmental sustainability of components. The results confirm the feasibility of developing effective and environmentally safe detergents.

Modern society relies heavily on synthetic detergents—from laundry powders to dishwashing liquids. However, most traditional ingredients, particularly anionic surfactants (AS) and phosphates, degrade poorly in the natural environment, leading to consequences such as eutrophication, disruption of aquatic ecosystems, and bioaccumulation in organisms.

According to data [1, 2], tens of thousands of tons of surfactants enter the environment annually, with the majority exerting toxic effects on aquatic life and lowering drinking water quality. This highlights the urgent need for eco-friendly and biodegradable alternatives.

Mass usage of synthetic detergents in household and industrial applications is associated with significant environmental risks, including the contamination of aquatic ecosystems with persistent organic substances and disruption of environmental biochemical processes.

The widespread use of synthetic detergents contributes to water pollution, ecosystem disruption, and human health risks. Traditional components such as linear alkylbenzene sulfonates (LAS), phosphates, and synthetic fragrances have low biodegradability and cause eutrophication and toxicity to aquatic fauna. In the context of rising environmental awareness, there is a growing demand for "green" detergent formulations in line with principles of sustainable development and green chemistry.

Table 1. Criteria for Environmentally Safe Optimization of Synthetic Detergents

Criterion	Description	Environmental Significance
Component Biodegradability	Ability to decompose by microorganisms	Reduces residual pollution
Aquatic Toxicity	Impact on fish, daphnia, algae, etc.	Risk assessment for ecosystems
Phosphate Content	Concentration of phosphorus-containing substances	Directly influences water eutrophication
Human Impact	Allergenic or irritant potential	Ensures safety during prolonged exposure
Use of Renewable Raw Materials	Application of plant-based surfactants and natural additives	Promotes sustainable resource use

Environmental Issues of Conventional Detergents

Surfactants

Anionic surfactants, especially LAS, are the most widely used and exhibit poor anaerobic biodegradability and high aquatic toxicity.

Phosphate-Based Components

Phosphates are a major contributor to eutrophication, promoting rapid algae growth and depleting oxygen in water bodies.

Additives

Additional components such as synthetic dyes, fragrances, and preservatives (e.g., formaldehyde donors) can be persistent, bioaccumulative, and allergenic.

Principles of Environmentally Safe Optimization
Phosphate Substitution

Environmentally safe alternatives to phosphates include:

- **Citrates** – easily biodegradable and safe;
- **Zeolites** – efficient ion-exchangers, non-biodegradable but non-toxic;
- **Carbonates and Silicates** – inexpensive and non-toxic, but less effective in hard water.

Table 2. Comparative Assessment of Detergent Composition Before and After Optimization

Parameter	Standard SD (before optimization)	Environmentally Optimized SD
Anionic Surfactants (e.g., SLS)	12%	5%
Nonionic Surfactants (e.g., APG)	0%	8%
Phosphates	15%	0%
Zeolites	0%	10%
Biodegradability (28 days), %	45%	85%
Residual Toxicity (mg/L)	2.4	0.6

Green Surfactants
Biodegradable surfactants based on renewable raw materials:

- **Alkyl polyglucosides (APG)** – from starch and fatty alcohols;
- **Methyl ester sulfonates (MES)** – derived from plant oils;
- **Sorbitan and coconut oil derivatives** – low toxicity and fast degradation.

Elimination of Harmful Additives

- Avoidance of microplastics and persistent organic pollutants;
- Replacement of synthetic dyes with natural alternatives;

- Use of essential oils instead of synthetic fragrances.

Methodology for Environmental Optimization
An effective eco-friendly optimization strategy includes:

- **Functional testing:** evaluating cleaning ability, foaming, etc.;
- **Biodegradability testing:** e.g., OECD 301F standard;
- **Ecotoxicological testing:** indicators such as LC50, EC50;
- **Life Cycle Assessment (LCA):** quantifies environmental impact from raw material extraction to disposal.

Table 3. Potential Substitutes for Harmful Components

Harmful Component	Alternative	Advantage	Limitation
Sodium lauryl sulfate	Lauryl glucoside	Low toxicity, biodegradable	Lower foaming power
Phosphates	Zeolites, citrates, phytates	Do not cause eutrophication	May require higher usage volume
EDTA	Iminodiacetate (IDA), GLDA	Higher biodegradability	More expensive to produce
Formaldehyde preservatives	Sodium benzoate, sorbic acid esters	Safer for skin	Less effective in high humidity

Maintaining a balance between environmental performance, economic feasibility, and consumer safety is essential.

Results and Discussion

Case studies demonstrate that replacing LAS with APG and phosphates with citrates or zeolites reduces aquatic toxicity by over 60% while preserving adequate cleaning performance. Comprehensive LCA analysis shows such substitutions can lower overall environmental impact by 30–50%, depending on production and energy conditions.

Conclusion

Environmentally oriented optimization of synthetic detergent formulations is a key strategy for reducing anthropogenic impact on ecosystems. Integrating green surfactants, biodegradable components, and safe additives aligns with the goals of sustainable development and current environmental standards (EU Ecolabel, REACH, EPA Safer Choice). Future research should focus on scaling up new formulations and reducing production costs.

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