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PRODUCTION OF ENVIRONMENTALLY FRIENDLY REAGENTS FROM SECONDARY RAW MATERIALS

Urolov Nodirbek Dilmurot o‘g‘li
Tashkent State Technical University
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ABSTRACT

This thesis examines the possibilities of producing environmentally friendly reagents from secondary raw materials and industrial by-products. Particular attention is paid to waste cooking oil, lignin-containing residues, agricultural biomass, and other renewable or recycled resources that can be used for the production of flotation collectors, depressants, dispersants, and biosurfactants. The environmental and economic advantages of such reagents are analyzed in terms of waste reduction, resource efficiency, biodegradability, lower dependence on petrochemical raw materials, and potential reduction of production costs. The study also considers the technological requirements for the practical application of secondary-resource-based reagents, including selectivity, adsorption properties, toxicity, stability, and industrial scalability. The results indicate that the conversion of secondary products into functional reagents can contribute to the development of green chemistry, circular economy principles, and sustainable mineral-processing technologies.

Keywords: secondary raw materials, environmentally friendly reagents, flotation reagents, waste cooking oil, lignin, biosurfactants, green chemistry, circular economy, sustainable mineral processing.

Introduction

The rapid development of modern industry has led to a significant increase in the generation of secondary raw materials, industrial by-products, and various waste streams. Many of these materials still contain valuable organic and inorganic compounds that can be recovered and reused in the production of functional chemical reagents. At the same time, conventional reagents used in mineral processing, metallurgy, chemical technology, and other industrial sectors may be associated with high production costs, dependence on primary raw materials, toxicity, poor biodegradability, and environmental pollution. Therefore, the development of environmentally friendly reagents from secondary raw materials is becoming an increasingly important direction of green chemistry and sustainable industrial development [1].Green chemistry is focused on the design of chemical products and technological processes that reduce or eliminate the use and generation of hazardous substances. Its main principles include waste prevention, efficient use of raw materials, reduction of toxicity, improvement of energy efficiency, and the application of renewable or alternative resources [1]. From this perspective, industrial by-products and wastes should not be considered only as materials requiring disposal, but also as promising secondary sources of valuable chemical compounds.

The utilization of secondary raw materials is closely connected with the concept of the circular economy. Unlike the traditional linear model of “raw material–production–consumption–waste,” the circular economy aims to return useful

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components into the production cycle, extend the life cycle of materials, and reduce the consumption of virgin resources. The use of secondary resources can contribute to the conservation of natural resources and reduce the environmental burden of industrial production, provided that recycling and processing technologies are technically and economically efficient [2].One of the promising directions is the production of environmentally friendly flotation and surface-active reagents from secondary organic raw materials. Conventional flotation processes require different types of collectors, frothers, depressants, and modifying agents. Many traditional flotation reagents are produced from petroleum-based raw materials and may have negative environmental effects. Therefore, the development of reagents based on renewable resources and industrial by-products has attracted increasing scientific interest.

Lignin is one of the important examples of a secondary raw material that can be used for the production of functional reagents. It is generated in significant quantities as a by-product of the pulp, paper, wood-processing, and biorefinery industries. Due to the presence of hydroxyl, carboxyl, methoxy, and other functional groups in its structure, lignin can be chemically modified and used as a collector, depressant, dispersant, or surface-active reagent. Recent studies have demonstrated the considerable potential of lignin-based flotation reagents as more sustainable and biodegradable alternatives to certain conventional chemicals used in mineral processing [3].Another promising secondary material is waste cooking oil. It contains fatty acids and their derivatives, which can serve as raw materials for the synthesis of surface-active compounds and flotation collectors. The conversion of waste cooking oil into useful chemical reagents provides a dual environmental benefit by reducing waste disposal problems and decreasing the consumption of primary petroleum-based feedstocks. Recent research has shown that collectors synthesized from waste cooking oil can provide effective and selective flotation of iron-containing minerals, including hematite [4].

The production of environmentally friendly reagents from secondary raw materials can provide several important advantages. These include the reduction of industrial waste, more efficient utilization of material resources, lower demand for virgin raw materials, decreased dependence on imported chemical reagents, potential reduction of production costs, and improvement of the environmental safety of technological processes. In addition, the introduction of secondary resources into reagent production can contribute to the implementation of circular economy principles and the development of low-waste industrial technologies [2].However, the successful industrial application of such reagents requires detailed investigation of the chemical composition of secondary raw materials, methods of reagent synthesis and modification, technological efficiency, selectivity, biodegradability, toxicity, production cost, and environmental impact. Therefore, the development of efficient technologies for converting secondary products into environmentally friendly reagents is an important scientific and practical task.The main objective of this study is to investigate the potential use of secondary raw materials for the production of environmentally friendly reagents and to evaluate their technological, environmental, and economic advantages compared with conventional chemical reagents.

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The transition toward sustainable mineral processing requires not only improvements in technological efficiency but also the replacement of conventional chemical reagents with safer and more sustainable alternatives. Flotation is one of the most widely used methods for the separation and concentration of valuable minerals, and its efficiency largely depends on the properties of collectors, frothers, depressants, dispersants, and other modifying reagents. However, a considerable proportion of conventional flotation reagents are synthesized from non-renewable petrochemical raw materials and may demonstrate toxicity, limited biodegradability, or persistence in the environment. Therefore, the development of reagents from secondary raw materials provides an important opportunity to combine technological efficiency with environmental protection [5].

Secondary Raw Materials as a Source of Green Reagents

Secondary raw materials include industrial by-products, agricultural and forestry residues, used oils, biomass-processing residues, and other materials generated during production or consumption. Instead of being disposed of, these materials can be processed chemically, physically, or biochemically to obtain compounds with useful surface-active properties.The selection of a suitable secondary raw material depends on its chemical composition, availability, stability, cost, and potential for modification. Materials rich in fatty acids, lignin, cellulose derivatives, carbohydrates, proteins, and other organic functional groups are particularly attractive because these compounds can interact with mineral surfaces and influence their wettability, hydrophobicity, and flotation behavior [5, 6].

An environmentally friendly flotation reagent should ideally combine several characteristics: low toxicity, high biodegradability, high selectivity toward the target mineral, availability of sustainable raw materials, low production cost, and minimal generation of hazardous by-products. Current approaches to green flotation reagent development therefore consider not only flotation recovery but also the origin of the feedstock, reagent toxicity, biodegradability, and environmental impact of the production process [5].

Waste Cooking Oil-Based Reagents

Waste cooking oil is one of the promising secondary raw materials for producing surface-active reagents. Large quantities of used vegetable oils are generated by households, restaurants, and food-processing industries. Direct disposal of these oils can create environmental problems, while their chemical composition makes them suitable for conversion into value-added products.Waste cooking oils usually contain significant amounts of fatty acids and triglyceride-derived compounds. Through processes such as hydrolysis and saponification, these components can be converted into compounds with surface-active properties. Fatty-acid salts obtained by saponification can interact with active sites on mineral surfaces and act as flotation collectors.

Recent studies have demonstrated that waste cooking oil can be converted into an effective collector for hematite flotation. Waste cooking oil soap exhibited preferential adsorption on hematite surfaces compared with quartz. Under optimized experimental conditions, hematite recovery reached 94.5%, while quartz recovery remained below 8%, indicating considerable selectivity of the waste-derived reagent [4]. Such results demonstrate that secondary oil resources can potentially replace or partially substitute conventional fatty-acid collectors.The use of waste oil as a raw

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material may also provide economic advantages because the initial feedstock has relatively low value and requires proper disposal. Its conversion into an industrial reagent transforms a waste stream into a useful technological product and contributes to circular resource utilization.

Lignin-Based Reagents

Lignin represents another important secondary raw material with considerable potential in flotation technology. It is generated in large amounts as a by-product of wood-processing, pulp and paper production, and biorefinery operations. Structurally, lignin is a complex aromatic biopolymer containing hydroxyl, methoxy, carboxyl, and other functional groups capable of interacting with mineral surfaces.The chemical structure of lignin can be modified to alter its solubility, charge, molecular weight, and surface activity. Depending on the type of modification and mineral system, lignin-derived compounds may function as depressants, dispersants, collectors, or modifiers. This versatility makes lignin an attractive platform for the development of new environmentally compatible flotation reagents [6].

Recent research emphasizes that lignin-based reagents may help reduce dependence on petroleum-derived flotation chemicals while creating value from an abundant industrial by-product. Their renewable origin, functional diversity, and possibility of chemical modification provide significant advantages for sustainable mineral processing [6]. Nevertheless, further optimization is required because lignin composition may vary depending on biomass origin and industrial extraction technology.

Biosurfactants and Biobased Reagents

Another important direction is the development of biosurfactants obtained from renewable and secondary biological resources. Biosurfactants contain both hydrophilic and hydrophobic groups and can therefore modify the interfacial properties between minerals, water, and air.Sugar-based surfactants, fatty-acid derivatives, fatty-alcohol-based compounds, and biologically synthesized surface-active molecules have attracted increasing attention as possible substitutes for conventional petrochemical flotation reagents [7]. Enzymatic production routes are particularly interesting because they may operate under relatively mild reaction conditions and can reduce the formation of undesirable reaction by-products.

Biobased collectors have also been investigated for phosphate ore flotation. These reagents may be produced from plant-derived oils, fatty acids, biomass components, or secondary biological resources. Their ability to adsorb selectively on mineral surfaces may provide effective flotation while reducing reliance on non-renewable raw materials [8].However, the term “green reagent” should not be applied solely because a reagent is derived from biomass. A comprehensive environmental assessment should consider toxicity, biodegradability, raw-material origin, synthesis conditions, energy consumption, reagent dosage, and waste generation throughout the reagent life cycle [5].

Table 1. Potential Secondary Raw Materials for the Production of Environmentally Friendly Reagents

Secondary raw material	Main valuable components	Possible reagent/product	Potential application	Main environmental and technological

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				advantages
Waste cooking oil	Fatty acids, triglyceride derivatives	Fatty-acid salts, soaps, collectors	Hematite and oxide mineral flotation	Waste utilization, low-cost feedstock, reduced use of virgin fatty acids [4]
Lignin-containing industrial by-products	Aromatic polymer, hydroxyl and carboxyl functional groups	Depressants, dispersants, collectors, modifiers	Mineral flotation and surface modification	Renewable origin, abundant industrial by-product, chemically modifiable [6]
Agricultural and biomass residues	Cellulose, starch, lignocellulose, natural polymers	Depressants and dispersants	Selective mineral separation	Biodegradability and reduced dependence on petroleum-based chemicals [5]
Secondary plant-oil resources	Fatty acids and lipid compounds	Anionic collectors and surfactants	Phosphate and oxide flotation	Renewable or recycled feedstock, possibility of replacing synthetic fatty-acid collectors [8]
Biomass-derived sugars and fatty alcohols	Carbohydrates and amphiphilic compounds	Biosurfactants	Flotation collectors and auxiliary reagents	Potential biodegradability, tunable molecular structure, green synthesis possibilities [7]

Environmental and Economic Efficiency

The environmental advantage of secondary-raw-material-based reagent production is primarily associated with simultaneous waste reduction and replacement of virgin chemical feedstocks. The utilization of waste oils, lignin-rich by-products, and biomass residues can reduce the volume of materials requiring disposal and create additional value from existing industrial streams.From an economic point of view, the final efficiency of a green reagent depends on several factors, including the cost of the secondary feedstock, transportation, purification requirements, chemical modification, reagent dosage, mineral recovery, selectivity, and the possibility of industrial-scale production. A reagent derived from inexpensive waste may not necessarily be economically advantageous if complicated purification or synthesis procedures are required. Therefore, technological and economic evaluation should be performed together.

In flotation processes, selectivity is particularly important. A reagent that provides high recovery but also floats significant amounts of gangue may increase

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subsequent processing costs. Consequently, the most promising secondary-resource-based reagents are those that simultaneously provide high recovery, high selectivity, environmental safety, and acceptable production costs. The results obtained with waste cooking oil-derived collectors illustrate that waste-based reagents can, under optimized conditions, demonstrate competitive flotation performance [4].In addition, lignin and other biomass-derived compounds provide possibilities for molecular modification. Functionalization makes it possible to adjust the adsorption behavior of the reagent toward particular mineral surfaces and thereby improve separation selectivity [6]. Biosurfactants and biobased collectors offer similar opportunities because their hydrophilic and hydrophobic groups can be tailored to achieve desired surface interactions [7, 8].

Thus, the development of environmentally friendly reagents from secondary products should be considered as a multidisciplinary task involving waste valorization, green chemistry, surface chemistry, mineral processing, environmental assessment, and economic analysis. The most effective technologies are expected to be those that use locally available secondary resources, require relatively simple processing, demonstrate stable reagent properties, and provide flotation efficiency comparable with or superior to conventional reagents.

CONCLUSION

The production of environmentally friendly reagents from secondary raw materials represents a promising approach for the development of sustainable chemical and mineral-processing technologies. The analysis shows that industrial by-products and secondary resources such as waste cooking oil, lignin-containing residues, agricultural biomass, plant-derived oils, and other organic waste materials can serve as valuable feedstocks for the production of collectors, depressants, dispersants, biosurfactants, and other functional reagents.The utilization of secondary raw materials provides both environmental and economic advantages. From an environmental perspective, this approach contributes to waste reduction, more efficient use of natural resources, decreased consumption of virgin petrochemical feedstocks, and the development of biodegradable or less toxic alternatives to conventional industrial reagents. These principles are consistent with the concepts of green chemistry and the circular economy, which emphasize waste prevention, resource efficiency, safer chemical processes, and the reintegration of secondary materials into production cycles.Among the investigated secondary resources, waste cooking oil demonstrates significant potential as a raw material for flotation collectors. Its fatty-acid-containing components can be converted into surface-active compounds capable of selective interaction with mineral surfaces. Studies on hematite flotation have demonstrated that waste cooking oil-derived collectors can achieve high mineral recovery and good selectivity, indicating their potential as alternatives to conventional petroleum-derived reagents.Lignin is another particularly promising secondary resource. Due to its complex structure and the presence of various functional groups, lignin can be chemically modified to produce collectors, depressants, dispersants, and other flotation reagents. Its abundance as an industrial by-product and its renewable origin make lignin attractive for the development of sustainable mineral-processing technologies.

Biobased surfactants and collectors obtained from renewable and secondary biological resources also show considerable potential. Their molecular structures can

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be modified to improve adsorption, selectivity, and flotation performance. Furthermore, enzymatic and other green synthesis approaches may reduce the environmental impact associated with reagent production.However, the environmental origin of a reagent alone does not guarantee its overall sustainability. The practical application of secondary-resource-based reagents requires a comprehensive assessment of toxicity, biodegradability, reagent dosage, selectivity, production energy requirements, purification costs, availability of raw materials, and industrial scalability. Therefore, future studies should focus on optimizing reagent synthesis, evaluating long-term environmental effects, performing techno-economic analyses, and conducting pilot-scale and industrial flotation tests.In conclusion, the conversion of secondary products into environmentally friendly reagents can simultaneously address the problems of industrial waste management, resource conservation, and sustainable chemical production. The implementation of such technologies can reduce dependence on conventional petrochemical reagents, promote circular utilization of resources, and improve the environmental sustainability of mineral processing and related industries. Further development and industrial implementation of secondary-raw-material-based reagents should therefore be considered an important direction for green chemistry and sustainable industrial development.

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