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Application and Effectiveness of Guanidine-Based Reagents in the Mining Industry

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Abstract: This article examines the application and effectiveness of guanidine-based reagents in the mining industry, with particular emphasis on their potential use in mineral processing, ore beneficiation, and flotation technologies. Guanidine-containing compounds have attracted increasing attention as promising chemical reagents because of their ability to interact with mineral surfaces and modify their physicochemical properties. The study focuses on the role of guanidine-based reagents in improving the selective separation of valuable minerals from gangue materials, particularly in the processing of complex and finely disseminated ores. Their chemical structure, surface activity, adsorption behavior, and interaction with mineral components are considered as important factors determining reagent performance. The analysis demonstrates that the application of guanidine-based reagents can contribute to an increase in the recovery of valuable mineral components while maintaining or improving concentrate quality under appropriate technological conditions. Their effectiveness is particularly associated with the possibility of achieving more selective interaction with specific mineral surfaces. At the same time, the technological performance of guanidine-based reagents depends strongly on ore mineralogy and process parameters, which makes optimization of their dosage and operating conditions essential. The article also considers the economic and environmental aspects of their application, including reagent consumption, process efficiency, potential reduction in the use of conventional chemical reagents, and the need to assess the toxicity, biodegradability, and environmental persistence of individual guanidine derivatives.

Keywords: Guanidine-Based Reagents, Mining Industry, Mineral Processing, Ore Beneficiation, Flotation, Mineral Surface, Selective Separation, Collectors, Reagent Efficiency, Recovery, Concentrate Quality, Environmental Efficiency

1. Introduction

The mining industry plays a strategically important role in the development of modern economies, providing essential mineral raw materials for metallurgy, energy production, construction, chemical manufacturing, and high-technology industries. At the same time, the extraction and processing of mineral resources are becoming increasingly complicated because of the gradual depletion of high-grade deposits, increasing quantities of finely disseminated ores, complex mineralogical compositions, and growing requirements for the efficient utilization of mineral resources. Under these conditions, improving mineral processing technologies and developing selective, environmentally acceptable, and economically efficient reagents have become important directions in the modernization of the mining sector. In particular, flotation and related physicochemical separation processes require reagents capable of selectively modifying mineral surfaces and improving the recovery and selectivity of valuable components.[1]

Among the different classes of flotation and mineral-processing reagents, guanidine-based compounds have attracted considerable scientific and practical interest because of their distinctive chemical structure and ability to interact with mineral surfaces. Guanidine and its derivatives contain nitrogen-rich functional groups that can participate in protonation, hydrogen bonding, electrostatic interactions, and surface complexation. These properties make guanidine-based reagents potentially useful as collectors, activators, modifiers, or auxiliary reagents in the beneficiation of various mineral ores. Their effectiveness is particularly relevant in the treatment of ores in which conventional collectors demonstrate insufficient selectivity or recovery.

The chemical characteristics of guanidine-based reagents provide a basis for their interaction with mineral surfaces of different compositions. Depending on the molecular structure and operating conditions, guanidine derivatives may exhibit cationic or amphoteric behavior and can be strongly influenced by pH, ionic strength, reagent concentration, pulp composition, and the presence of competing ions. The protonation state of the guanidine functional group is especially important because it determines the reagent's charge and consequently affects its adsorption behavior at the mineral–water interface. Therefore, the effectiveness of guanidine-based reagents cannot be evaluated independently of the physicochemical conditions of the flotation pulp.[2]

The application of guanidine-based reagents is particularly promising for the beneficiation of complex and polymetallic ores. Such ores frequently contain several minerals with similar surface properties, making selective separation difficult. Conventional collectors may adsorb simultaneously on valuable and gangue minerals, resulting in reduced concentrate quality and increased reagent consumption. Guanidine derivatives, owing to their specific functional groups and surface interactions, can potentially provide greater selectivity toward particular mineral phases. This characteristic is important in the recovery of valuable minerals from low-grade and finely disseminated deposits, where relatively small differences in surface chemistry can determine the efficiency of separation.[3]

The growing importance of reagent selectivity is also associated with the economic challenges facing the mining industry. Mineral processing accounts for a significant proportion of the total operating costs of many mining enterprises, including expenditures on grinding, water, energy, equipment, and chemical reagents. The optimization of reagent regimes can therefore directly influence production costs and the overall economic efficiency of ore processing. A reagent that provides higher recovery at a lower dosage, improves concentrate grade, or reduces the need for additional processing stages may create substantial economic benefits. Consequently, the evaluation of guanidine-based reagents should include not only their chemical and technological performance but also their influence on reagent consumption, recovery rates, concentrate quality, and overall processing costs.

Another important factor is the increasing environmental pressure on the mining industry. Traditional mineral-processing reagents may have undesirable environmental characteristics, including toxicity, persistence, bioaccumulation potential, or negative effects on aquatic ecosystems. As environmental regulations become stricter, mining companies are increasingly interested in developing reagent systems that combine high metallurgical performance with lower environmental risks. In this context, guanidine-based reagents represent an interesting research direction. However, their environmental acceptability should not be assumed solely on the basis of their chemical structure. The toxicity, biodegradability, degradation products, residual concentrations, and behavior in process water must be evaluated experimentally for each specific compound and application.[4]

The effectiveness of guanidine-based reagents is determined by several interconnected mechanisms. The first is adsorption on the surface of the target mineral. Depending on the mineral composition and reagent structure, adsorption may occur through electrostatic attraction, chemical bonding, hydrogen bonding, or surface complex formation. The second mechanism involves modification of the surface wettability. In flotation, the selective transformation of a mineral surface from hydrophilic to relatively hydrophobic is a fundamental condition for attachment to air bubbles. Guanidine-based collectors may facilitate this transformation by forming an adsorbed layer on mineral particles. The third mechanism is related to the interaction between reagent molecules and dissolved species present in the pulp. Metal ions, hydroxyl species, dissolved oxygen, and other ions can significantly influence adsorption and flotation behavior.

pH is one of the most important operational parameters affecting the performance of guanidine-based reagents. Changes in pH modify both the surface charge of minerals and the ionization state of reagent molecules. At a particular pH range, the reagent may exhibit optimal adsorption on the desired mineral, while adsorption on gangue minerals remains comparatively weak. Therefore, determining the optimum pH range is essential for achieving high selectivity. Similarly, reagent dosage must be optimized because insufficient dosage may lead to incomplete surface coverage and low recovery, whereas excessive dosage can increase operating costs and may promote non-selective adsorption or adversely affect froth properties.[5]

Particle size is another critical parameter in the application of guanidine-based reagents. Fine grinding increases the liberation of valuable minerals from gangue but simultaneously increases the specific surface area of particles and may complicate flotation. Very fine particles can exhibit poor collision and attachment probabilities with air bubbles, while coarse particles may contain locked valuable minerals. The interaction between particle size distribution and reagent adsorption is therefore important when assessing the practical effectiveness of guanidine-based reagent systems. A reagent that performs well in laboratory tests with a narrow particle-size fraction may require further optimization before industrial application.

The mineralogical characteristics of the ore also play a decisive role. Differences in crystal structure, surface defects, oxidation state, lattice composition, and degree of liberation can substantially influence reagent adsorption. For sulfide, oxide, carbonate, and silicate minerals, the mechanisms of interaction with guanidine derivatives may differ considerably. In addition, surface oxidation during crushing, grinding, and storage can alter mineral reactivity and change flotation performance. Therefore, the application of guanidine-based reagents should be considered as part of an integrated mineral-processing system rather than as an isolated chemical treatment.[6]

From a technological perspective, the assessment of guanidine-based reagents requires a combination of laboratory flotation experiments and physicochemical characterization. Conventional flotation tests can be used to determine valuable-component recovery, concentrate grade, yield, and separation efficiency. Complementary methods such as adsorption measurements, zeta-potential analysis, Fourier-transform infrared spectroscopy, X-ray photoelectron spectroscopy, contact-angle measurements, and microscopic analysis can provide information about the mechanisms responsible for reagent–mineral interactions. Such approaches allow researchers to move beyond purely empirical optimization and establish relationships between molecular structure, surface chemistry, and flotation performance.

The comparison of guanidine-based reagents with conventional collectors is also essential. The practical value of a new reagent depends not simply on whether it produces flotation, but on whether it offers measurable advantages over existing technologies. Such advantages may include higher recovery, improved selectivity, lower reagent consumption, greater tolerance to variations in pulp chemistry, better performance with complex ores, or reduced environmental impact. In industrial practice, reagent cost and availability are also important considerations. A technically effective reagent may not be economically attractive if its synthesis is complicated, raw materials are expensive, or its supply is unstable.[7]

The development of guanidine-based reagent systems is particularly relevant for deposits containing valuable minerals that are difficult to separate using conventional technologies. As ore grades decline, the mining industry increasingly relies on advanced beneficiation methods to maintain production levels and improve resource utilization. Selective reagents can contribute to this objective by increasing the efficiency of separation at the mineral surface. In addition, the use of more effective reagents may reduce the amount of ore requiring repeated processing and potentially decrease energy and water consumption per unit of recovered metal.

The issue of water consumption is particularly important in modern mining. Flotation is normally conducted in aqueous media, and the recycling of process water can lead to the accumulation of dissolved ions and residual reagents. These changes may influence the performance of collectors and frothers and can make process control more difficult. Therefore, the stability of guanidine-based reagents under recycled-water conditions should be considered when evaluating their industrial applicability. Understanding their interactions with process-water components can contribute to the development of more robust reagent regimes and improve the consistency of flotation results.

Another promising direction is the combined use of guanidine-based reagents with other flotation reagents. Selective collectors may be used together with depressants, activators, frothers, pH regulators, or other collectors to achieve improved separation. Such reagent combinations can produce synergistic effects, but they may also lead to competitive adsorption and unpredictable changes in surface chemistry. Consequently, systematic experimental studies are necessary to determine appropriate reagent combinations and dosage ratios. The development of mixed collector systems may be particularly useful for complex ores containing several economically

valuable minerals.
The scientific relevance of studying guanidine-based reagents is therefore associated with the need to establish a clearer relationship between their molecular characteristics and their technological performance. Although the chemical functionality of guanidine provides significant potential for interaction with mineral surfaces, practical effectiveness depends on the mineralogical composition of the ore, pulp chemistry, reagent concentration, pH, particle size, oxidation conditions, and flotation regime. A comprehensive evaluation should consequently integrate chemical, physicochemical, technological, economic, and environmental criteria.[8]
The present article focuses on the application and effectiveness of guanidine-based reagents in the mining industry, with particular attention to their potential role in mineral flotation and beneficiation. The study considers the fundamental properties of guanidine-containing compounds, their interaction with mineral surfaces, the principal factors controlling their adsorption and flotation behavior, and their potential advantages compared with conventional reagent systems. Particular emphasis is placed on recovery, selectivity, reagent consumption, concentrate quality, and the possibility of improving the overall technological and economic performance of mineral-processing operations.
The relevance of this research is further strengthened by the current transition toward more resource-efficient and environmentally responsible mining technologies. The future competitiveness of mineral-processing enterprises will increasingly depend on their ability to recover valuable components from lower-grade and more complex ores while minimizing energy, water, and chemical consumption. Guanidine-based reagents may provide one of the chemical-technological approaches for addressing these challenges. Their systematic investigation can contribute to the development of optimized flotation regimes, improved utilization of mineral resources, and the creation of more efficient and sustainable beneficiation technologies.

2. Methodology

This study employs a comprehensive analytical and experimental methodology to investigate the application and effectiveness of guanidine-based reagents in the mining industry, with particular emphasis on their potential use in mineral beneficiation and flotation processes. The methodological approach combines a review of scientific literature, physicochemical analysis of guanidine-based compounds, evaluation of their interaction with mineral surfaces, comparative assessment of flotation performance, and analysis of technological, economic, and environmental efficiency. The research is structured around the relationship between the chemical characteristics of guanidine-based reagents and their ability to selectively modify mineral surfaces and improve the separation of valuable minerals from gangue materials. Initially, scientific publications, technical reports, industrial studies, and relevant methodological sources concerning guanidine derivatives and their application in mineral processing were analyzed. Particular attention was paid to studies dealing with flotation of sulfide, oxide, and other technologically important minerals, as well as research examining the influence of reagent structure, dosage, pulp pH, particle size, and reagent combinations on mineral recovery. The collected information was systematized according to the type of mineral, type and concentration of reagent, flotation conditions, recovery rate, concentrate grade, selectivity, and environmental characteristics.[9]
The physicochemical properties of guanidine-based reagents were analyzed as an important methodological component because their effectiveness is closely associated with molecular structure, basicity, solubility, surface activity, and protonation behavior in aqueous media. The guanidino functional group possesses strong basic characteristics, which can affect the interaction between reagent molecules and mineral surfaces under different pulp conditions. Therefore, the research considers the influence of pH on reagent speciation and adsorption behavior. Particular attention is given to the relationship between the concentration of hydrogen ions, reagent protonation, mineral surface charge, and the resulting hydrophobicity of mineral particles. These relationships are important for determining whether a guanidine-based reagent can function as an effective collector or modifier during flotation.
Mineral samples used for comparative evaluation are considered in terms of their chemical and mineralogical composition. Prior to flotation testing, ore samples are subjected to crushing, grinding, homogenization, and particle-size classification in order to obtain representative material

with an appropriate degree of mineral liberation. The chemical composition of the ore is determined using appropriate analytical techniques, while mineralogical composition can be established using X-ray diffraction, X-ray fluorescence, scanning electron microscopy with energy-dispersive spectroscopy, or other instrumental methods. Particular attention is paid to the concentration of valuable components and the proportion of gangue minerals because these characteristics directly influence reagent selectivity and overall beneficiation efficiency. The particle-size distribution of the ground material is also considered, since excessively coarse particles may have insufficient liberation, whereas excessive grinding can produce fine particles and slimes that negatively affect flotation selectivity.

The interaction between guanidine-based reagents and mineral surfaces is investigated through the analysis of adsorption and changes in surface properties. The adsorption process is interpreted as the key mechanism responsible for the modification of mineral particles and their subsequent separation during flotation. Depending on the available analytical facilities, adsorption behavior can be investigated through zeta-potential measurements, contact-angle analysis, FTIR spectroscopy, and other surface-characterization techniques. Zeta-potential measurements are used to determine changes in the electrical characteristics of mineral surfaces after reagent treatment, while contact-angle measurements provide information about changes in surface hydrophobicity. FTIR analysis can be used to identify characteristic functional groups and possible chemical interactions between reagent molecules and mineral surfaces. The combined interpretation of these parameters makes it possible to distinguish between physical adsorption and stronger chemical interactions and to determine the conditions under which guanidine-based reagents demonstrate the highest surface activity.

The flotation experiments are designed to evaluate the technological effectiveness of guanidine-based reagents under controlled laboratory conditions. A series of tests is conducted by varying the principal technological parameters, including reagent dosage, pulp pH, conditioning time, flotation time, solid concentration, particle-size distribution, and the presence of auxiliary reagents. A baseline experiment without the investigated guanidine-based reagent is used for comparison, while conventional collectors may be tested under equivalent conditions as reference reagents. Such an experimental design allows the contribution of the guanidine-based component to the flotation process to be separated from the effects of other technological parameters. Each experimental condition is preferably repeated to improve the reliability and reproducibility of the results, and average values are used for subsequent analysis.

The effectiveness of the reagents is evaluated using several technological indicators rather than a single performance parameter. The principal indicators include the recovery of the target mineral, concentrate grade, selectivity, reagent consumption, and overall mass balance. Mineral recovery is calculated as the proportion of the valuable component transferred from the feed into the concentrate. Concentrate grade is determined by measuring the concentration of the target valuable component in the obtained concentrate. The selectivity of the reagent is assessed by comparing the recovery of the target mineral with the recovery of undesirable gangue components. A reagent is considered technologically effective when it produces an increased recovery and/or concentrate grade without causing an unacceptable increase in gangue recovery or reagent consumption.[10]

Environmental considerations are incorporated into the methodology because the introduction of new flotation reagents must be evaluated not only in terms of technological efficiency but also in terms of potential environmental impacts. The analysis considers reagent toxicity, biodegradability, persistence in process water, potential effects on aquatic organisms, and the possibility of reagent residues entering tailings or wastewater. The environmental performance of guanidine-based reagents is compared with that of conventional collectors where sufficient information is available. Particular attention is given to the possibility of reducing reagent consumption while maintaining high mineral recovery, as lower reagent consumption may contribute to a reduction in the chemical load of flotation wastewater and tailings.

Statistical analysis is used to determine the reliability of experimental results and the significance of differences between reagent systems. Descriptive statistics, including mean values, standard deviations, and coefficients of variation, are calculated for repeated experiments. Where the experimental design permits, analysis of variance can be applied to determine the significance of the effects of reagent dosage, pH, conditioning time, and other factors on mineral recovery and

concentrate grade. Correlation and regression analysis may also be used to identify relationships between reagent concentration and technological indicators. The statistical significance level is set at an appropriate conventional threshold, while confidence intervals are considered when interpreting differences between experimental groups.
Finally, the results obtained from the physicochemical, technological, economic, and environmental analyses are integrated into a comprehensive assessment of guanidine-based reagent effectiveness. The methodological framework makes it possible to determine not only whether guanidine-based reagents improve mineral recovery, but also under what technological conditions they demonstrate their greatest potential. The final assessment therefore considers the combined effect of reagent chemistry, mineral composition, flotation conditions, selectivity, reagent consumption, economic efficiency, and environmental performance. This integrated methodology provides a scientific basis for determining the feasibility of guanidine-based reagents as alternative or complementary reagents in modern mineral-processing technologies and for identifying directions for their further optimization and industrial application.

3. Results and Discussion

The analysis of the application of guanidine-based reagents in the mining industry demonstrates that these compounds have significant potential as alternative or complementary reagents in mineral processing, particularly in flotation-based beneficiation. Their effectiveness is primarily associated with the presence of the guanidinium functional group, which can interact with mineral surfaces through electrostatic attraction, hydrogen bonding, surface complexation, and, depending on mineral composition and operating conditions, stronger chemical interactions. These characteristics make guanidine-based reagents particularly relevant to the selective separation of minerals with different surface properties.[11]
Guanidine-based compounds possess a strongly basic functional group capable of existing in protonated form under aqueous conditions. This property is important for mineral processing because the surface charge of minerals and the ionic form of the reagent are strongly dependent on pulp pH. Under acidic and moderately acidic conditions, guanidine groups tend to become protonated, which can promote their adsorption onto negatively charged mineral surfaces.
The general interaction between a protonated guanidine species and a negatively charged mineral surface can be represented conceptually as:
where the interaction may initially be electrostatic and may subsequently be strengthened through hydrogen bonding or surface chemical interactions.
This mechanism is particularly important for minerals whose surfaces acquire negative charge in the relevant pH range. Consequently, the effectiveness of guanidine-based reagents cannot be considered independently of mineralogy, pulp chemistry, particle size, water composition, and pH.
One of the principal areas in which guanidine-based reagents demonstrate practical potential is froth flotation. In flotation, reagent performance is commonly evaluated through indicators such as recovery, concentrate grade, selectivity, flotation rate, and reagent consumption.
The recovery of a valuable mineral can be expressed as:
where represents the mass of concentrate, is the concentration of the valuable component in the concentrate, is the mass of feed, and is the concentration of the valuable component in the feed.
The use of guanidine-based collectors can affect both components of this relationship. Enhanced adsorption on the target mineral increases its hydrophobicity and consequently promotes its transfer into the froth phase. At the same time, the selectivity of the reagent determines whether unwanted gangue minerals are also recovered.[12]
The results of the reviewed technological approaches indicate that guanidine-based reagents are most promising when their adsorption is sufficiently selective. In such circumstances, an increase in recovery can be accompanied by an increase or stabilization of concentrate grade. However, excessive reagent concentration may result in non-selective adsorption, increasing gangue recovery and reducing concentrate quality.
Therefore, the relationship between reagent concentration and recovery is not necessarily linear. At low concentrations, the mineral surface may remain insufficiently covered, whereas increasing the concentration promotes collector adsorption. After reaching an effective surface-coverage level, further increases may provide limited additional recovery and may even negatively affect

selectivity.
Reagent dosage is one of the most important technological parameters affecting the efficiency of guanidine-based flotation systems. The experimental relationship can generally be divided into three characteristic zones.
In the first zone, corresponding to low reagent concentrations, the number of active guanidine molecules available for mineral-surface interaction is insufficient. As a result, only a portion of the potentially floatable mineral surface becomes hydrophobized. Flotation recovery therefore remains relatively low.
In the second zone, an increase in reagent concentration produces a substantial improvement in recovery. This corresponds to more complete coverage of active adsorption sites and improved formation of hydrophobic surface regions.
In the third zone, further increases in reagent dosage produce relatively small improvements in recovery or may even reduce concentrate selectivity. Excess reagent can increase adsorption on non-target minerals, modify pulp chemistry, increase froth stability, or promote the formation of multilayer surface structures.
Accordingly, the optimum guanidine reagent dosage should be determined experimentally rather than established solely on the basis of reagent composition. The optimum point represents a compromise between maximum valuable-mineral recovery and acceptable concentrate grade.[13]
The pH of the flotation pulp has a particularly important influence on guanidine-based reagents because it controls both reagent protonation and mineral-surface charge. Changes in pH may therefore modify adsorption kinetics and reagent selectivity simultaneously.
At lower pH values, protonation of the guanidine group is favored. The resulting cationic species may demonstrate strong electrostatic attraction toward negatively charged mineral surfaces. However, excessively acidic conditions may alter mineral dissolution, increase the concentration of competing ions, or change the structure of the mineral surface.
At higher pH values, the degree of protonation decreases and hydroxylation of mineral surfaces becomes increasingly important. In addition, dissolved metal ions and hydrolyzed species may compete with the reagent for active adsorption sites.
Thus, pH optimization is essential for achieving selective adsorption. The most favorable pH interval depends on the mineralogical composition of the ore and the specific chemical structure of the guanidine-based reagent.
A major advantage of guanidine-based reagents is the possibility of modifying their molecular structure to improve selectivity. Substitution of organic groups around the guanidine functional group can alter molecular charge distribution, hydrophobicity, steric characteristics, and adsorption behavior.
This creates an opportunity to design reagents for particular mineral systems rather than relying on a universal collector.
Selectivity can be evaluated through the relationship between valuable-mineral recovery and gangue recovery. A useful qualitative indicator is the selectivity index:
where is the recovery of the valuable mineral and is the recovery of the principal gangue mineral.
A higher value of indicates that the reagent favors the valuable mineral relative to gangue. In practical flotation systems, however, this indicator should be interpreted together with concentrate grade, reagent consumption, and economic value.
The analysis indicates that guanidine-based reagents are particularly attractive when conventional collectors exhibit insufficient selectivity. Their application can therefore be viewed not simply as a replacement for existing reagents but as a method for improving the selectivity of complex flotation circuits.
The effectiveness of guanidine-based reagents is closely related to the physicochemical characteristics of mineral surfaces. Important surface properties include surface charge, density of active sites, oxidation state, degree of oxidation, crystal defects, and the presence of adsorbed ions.[14]
For oxidized or partially oxidized mineral surfaces, adsorption may differ substantially from adsorption on fresh mineral surfaces. Surface oxidation can generate hydroxyl groups and alter the distribution of active sites, thereby changing the interaction between the mineral and guanidine-based reagent.

The presence of dissolved ions is another important factor. Calcium, magnesium, iron, copper, lead, zinc, and other metal ions may act as activators or competitors depending on the mineral system. Such interactions can either enhance reagent adsorption or reduce its selectivity.

Therefore, laboratory tests conducted with pure mineral samples may not fully represent industrial ore behavior. Industrial ores contain multiple minerals and a complex aqueous phase, making the optimization of guanidine-based flotation systems more challenging.

Water quality is an important but sometimes underestimated parameter in mineral flotation. Industrial process water frequently contains dissolved inorganic salts, residual reagents, metal ions, and suspended fine particles.

These components can modify the adsorption of guanidine-based compounds. For example, multivalent cations can compress the electrical double layer around mineral particles and modify electrostatic interactions. Competing organic molecules may also occupy active surface sites.

Consequently, a guanidine reagent that demonstrates high efficiency in laboratory tests using distilled water may exhibit different performance in recycled industrial water.

This finding emphasizes the importance of conducting reagent optimization under conditions that reproduce actual processing-water chemistry. Such an approach can significantly improve the reliability of industrial-scale predictions.

Particle size also affects the effectiveness of guanidine-based reagents. Fine grinding increases the specific surface area of the ore and creates a larger number of potential adsorption sites. However, excessive grinding can generate slimes that adversely affect flotation.

Very fine particles have low collision probability with air bubbles and may also become entrained in the froth. In addition, slime coatings can cover the surfaces of valuable minerals and prevent direct interaction with the collector.

For this reason, the optimum reagent dosage must be considered together with the grinding regime. An increase in specific surface area may require an increased collector dosage, but excessive reagent consumption can reduce economic efficiency.

The results therefore support the use of integrated optimization in which grinding size, pulp density, conditioning time, reagent dosage, and flotation time are evaluated simultaneously.

The conditioning period determines the extent to which the reagent interacts with the mineral surface before flotation. Guanidine-based reagents require sufficient time to reach active adsorption sites and establish stable surface interactions.

At very short conditioning times, adsorption may be incomplete, resulting in lower flotation recovery. Increasing the conditioning time generally promotes reagent distribution across mineral particles. However, excessively long conditioning may not provide proportional improvements and can increase operating costs.[15]

4. Conclusion

The analysis of the application and effectiveness of guanidine-based reagents in the mining industry demonstrates that these compounds have considerable potential as alternative and highly selective reagents for the processing and beneficiation of mineral raw materials. Their chemical structure, strong basicity, ability to interact with mineral surfaces, and capacity to participate in adsorption and surface-modification processes make guanidine-based compounds particularly promising for flotation and related mineral-processing technologies. In comparison with conventional collectors and surface-active reagents, guanidine-based reagents can provide new opportunities for improving the selectivity of mineral separation, especially when the processing of complex and finely disseminated ores requires more controlled interactions between the reagent and the mineral surface. The effectiveness of guanidine-based reagents is determined by several interrelated factors, including the mineralogical composition of the ore, surface properties of the target minerals, reagent concentration, pulp pH, temperature, particle size, water chemistry, and flotation conditions. Therefore, the successful industrial application of these reagents cannot be based solely on their chemical activity. It requires systematic optimization of the entire reagent–mineral system. Appropriate adjustment of reagent dosage and pulp conditions is particularly important because excessive reagent consumption may increase processing costs and negatively affect the selectivity of separation, whereas insufficient dosage may result in inadequate mineral recovery. One of the principal advantages of guanidine-based reagents is their potential to increase the recovery of valuable minerals while maintaining an acceptable level of selectivity. Their adsorption on mineral surfaces can modify surface hydrophobicity and consequently influence the attachment of mineral particles to air bubbles during flotation. This characteristic is especially relevant for ores containing several minerals with similar physical properties, where conventional separation methods may demonstrate limited selectivity. The use of guanidine-based reagents can therefore contribute to the development of more targeted beneficiation schemes and improve the technological performance of mineral-processing plants. Overall, guanidine-based reagents can be regarded as a promising class of chemical agents for modern mineral-processing technologies. Their principal value lies in their ability to influence mineral-surface properties and potentially improve the selectivity and recovery of flotation processes. Their application may be particularly beneficial in the processing of complex ores where conventional reagent systems do not provide sufficient separation efficiency. Nevertheless, industrial adoption should be based on a comprehensive assessment combining technological efficiency, economic viability, environmental safety, and operational stability.

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