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APPLICATION OF CHELATING COLLECTORS IN SELECTIVE FLOTATION OF COMPLEX ORES - A SHORT REVIEW

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Abstract

The depletion of high-grade, easily processable sulfide ores has forced the mining industry to exploit complex, finely disseminated, and partially oxidized deposits. Under these challenging conditions, traditional sulfhydryl collectors often exhibit poor selectivity and low recovery rates. This short review evaluates the application of chelating collectors as a highly selective technological alternative for the flotation of complex ores. Unlike conventional reagents, chelating agents act as multidentate ligands, bonding with surface metal cations through specific donor atoms (such as oxygen, nitrogen, and sulfur) to form stable, cyclic coordination complexes. The mechanism of action is fundamentally governed by chemisorption, where the steric and geometric alignment of the ligand and precise pH regulation dictate the overall selectivity against silicate gangue minerals. This paper provides a comprehensive overview of the major classes of chelating collectors, including hydroxamates, oximes, carbamates, and quinoline derivatives. Furthermore, industrial implementation strategies are discussed, emphasizing the synergistic economic and kinetic benefits of using chelating agents as co-collectors in mixed formulations with traditional xanthates or fatty acids. Finally, the review addresses environmental considerations, highlighting the superior biodegradability and lower eco-toxicity of modern chelating structures in closed-loop water systems.

***Keywords**: Flotation, Chelating collectors, Complex ores, Chemisorption, Selectivity, Mixed collectors, Environmental impact.*

1. INTRODUCTION

Flotation is the most critical industrial method for concentrating base and precious metal ores. The success of this process directly depends on the selective hydrophobization of the target mineral surface using chemical reagents known as collectors. Traditional collectors, such as sulfhydryl reagents (xanthates and dithiophosphates), yield excellent results when processing simple sulfide ores [1]. However, modern mining faces the global depletion of high-grade deposits. Today, processing industries must deal with complex, finely disseminated, and partially oxidized ores [2]. Under these conditions, standard collectors lose their selectivity and efficiency, creating an urgent need for advanced chemical solutions [3].

In this challenging environment, chelating collectors represent a key technological breakthrough [4]. These reagents possess specific functional groups capable of forming stable, cyclic coordination complexes (chelates) with metal cations on the mineral surface [5]. Due to their distinct chemical specificity toward particular metal ions, chelating collectors enable the selective separation of minerals even when differences in their physical and chemical properties are minimal [6]. The historical development of these agents began with adapting analytical organic ligands for mineral processing applications [7]. The objective of this short review is to analyze the mechanism of action, the most prominent classes of chelating reagents, and their practical applications in modern flotation.

2. MECHANISM OF ACTION OF CHELATING REAGENTS

2.1. Formation of Surface Complexes

The mechanism of action of chelating collectors is based on chemisorption reactions occurring directly at the mineral-water interface [4]. Unlike conventional collectors that bind via simple electrostatic forces or monodentate bonds, a chelating molecule acts as a multidentate ligand [5]. It binds to a central metal ion on the mineral crystal lattice through two or more donor atoms—most commonly oxygen, nitrogen, sulfur, or phosphorus [6]. This binding mechanism results in the formation of stable five- or six-membered rings that effectively mask the hydrophilic sites on the mineral surface.

The steric and geometric structure of the ligand must exactly match the ionic radius of the target metal to achieve successful chelation [3]. The reaction for the formation of a stable surface complex can be expressed by the following general equation [4, 5]:

$$M^{n+} + L^{m-} \rightleftharpoons [M(L)]^{(n-m)+}$$

Where:

M^{n+}– the metal cation located on the mineral surface lattice

L^{m-}– the molecule or ion of the chelating collector (ligand)

2.2. The Role of pH and Selectivity

The selectivity of chelating collectors is directly governed by the stability constants of the formed complexes and the pH of the flotation pulp [7]. Because hydroxyl ions (OH^-) compete with the chelating ligands for binding with the surface metal cations, precise pH control is a critical factor for flotation success [2]. At the optimal pH range, the chelating collector forms a neutral, insoluble complex on the mineral surface. Once bound, the hydrophobic hydrocarbon chains of the reagent remain oriented toward the aqueous phase [8]. This drastically increases the overall hydrophobicity of the mineral particle, facilitating its attachment to passing air bubbles. One of the greatest advantages of these agents is their electronic configuration, which prevents them from reacting with silica or aluminum ions, providing exceptional selectivity against silicate gangue minerals [1].

3. OVERVIEW OF MAJOR CLASSES OF CHELATING COLLECTORS

Table 1 shows the major classes of chelating collectors used in flotation concentration.

Table 1. *Major classes of chelating collectors applied in flotation concentration*

Class of Chelating Collector	Donor Atoms	Main Flotation Application	References
Hydroxamates (e.g., alkyl hydroxamate)	Oxygen, Oxygen (O, O)	Flotation of iron oxides, rare earth minerals (bastnäsite), copper oxides, and malachite.	[4], [5]
Oximes (e.g., salicilaldoxime)	Nitrogen, Oxygen (N, O)	Highly selective flotation of copper oxides and copper sulfides from complex ores.	[3], [7]
Carbamates & Dithio-compounds	Sulfur, Sulfur (S, S)	Flotation of precious metals (gold, platinum) and complex lead-zinc sulfides.	[1], [6]
Quinoline Derivatives (e.g., 8-hydroxyquinoline)	Nitrogen, Oxygen (N, O)	Selective concentration of zinc oxide ores (smithsonite) under natural pH conditions.	[2], [8]

3.1. Hydroxamates

Hydroxamates are among the most commercially successful chelating collectors in the mining industry [4]. They exhibit exceptional selectivity toward trivalent metal cations such as Fe^{3+} , Al^{3+} , and RE^{3+} (rare earth elements) [5]. By forming highly stable five-membered rings, they allow for the efficient separation of valuable minerals from silicate gangue. Recent studies confirm their vital role in processing low-grade carbonatite rare earth ores [2].

3.2. Oximes and Their Derivatives

Oxime collectors bind specifically to copper (Cu^{2+}) and nickel (Ni^{2+}) ions [7]. Due to the geometric arrangement of their nitrogen and oxygen donor atoms, and depending on the pH environment, these reagents enable the direct flotation of malachite, azurite, and chrysocolla [8]. This eliminates the need for prior sulfidization stages, which are historically difficult to control and environmentally hazardous [3].

3.3. Carbamates and Dithio-compounds

Carbamates and dithiocarbamates exhibit an exceptional affinity for precious metals and heavy metal sulfides [1], [6]. Due to the presence of dual sulfur (S, S) donor atoms, these collectors form extremely stable four-membered or five-membered chelate rings on the surfaces of gold, platinum, galena, and sphalerite. Their high chemical selectivity allows for the efficient rejection of iron sulfides (like pyrite) without requiring excessive dosages of hazardous depressants [4].

3.4. Quinoline Derivatives

Quinoline derivatives, most notably 8-hydroxyquinoline, represent a highly advanced class of collectors used primarily for difficult-to-float zinc oxide minerals such as smithsonite [2], [No. 8]. By utilizing both nitrogen and oxygen (N, O) donor atoms, these reagents successfully bypass the traditional, poorly controlled sulfidization step. They bind directly to zinc cations under natural or slightly alkaline pH conditions, forming a highly hydrophobic surface layer that ensures clean separation from carbonate gangue [5].

4. INDUSTRIAL APPLICATION AND ENVIRONMENTAL ASPECTS

4.1. Synergistic Effects and Mixed Collector Systems

In industrial operations, chelating collectors are rarely used alone due to their high production costs and complex chemical synthesis [7]. Instead, they are typically applied as co-collectors in combination with cheaper, traditional collectors like fatty acids or xanthates [1]. This synergistic approach offers several distinct advantages:

1. It significantly reduces the overall consumption and cost of expensive chelating reagents [3].
2. It increases the recovery rate of the valuable mineral by 5% to 15% compared to single-collector systems [6].
3. It helps overcome the kinetic limitations of individual reagents when treating complex, multi-mineral skarn ores [2].

4.2. Environmental Impact and Biodegradability

Traditional sulfhydryl collectors can release toxic carbon disulfide (CS_2) or hazardous hydrogen sulfide (H□S) gas during decomposition [1]. In contrast, many

modern chelating collectors—especially those derived from amino acids or hydroxamic acids—are much more environmentally friendly [6]. They display higher rates of biodegradability in tailing ponds and lower acute toxicity toward aquatic ecosystems [8]. This simplifies water treatment processes, making it easier to recycle process water within closed-loop industrial systems.

5. CONCLUSION

The application of chelating collectors represents one of the most promising advancements in modern mineral processing theory and practice. Their ability to form highly stable and selective surface complexes successfully addresses the challenges of processing complex and oxidized ores that cannot be economically treated with traditional reagents.Although the initial cost of purchasing chelating agents is higher, their industrial implementation via synergistic mixtures with standard collectors yields clear economic benefits through improved metal recovery and cleaner, greener processesFuture research must focus on the computer-aided design (such as DFT simulations) of cost-effective, eco-benign chelating molecules and optimizing their behavior in complex polymetallic flotation circuits

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