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Review

Bridging flotation and dewatering chemistry: A review of flotation reagent effects on tailings coagulation-flocculation-sedimentation

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Abstract: Closing water circuits and dry-stacking tailings are now central goals of sustainable mineral processing, and both depend on the efficient coagulation-flocculation-sedimentation (C-F-S) of flotation tailings in thickeners. Flotation reagents, namely, collectors, frothers, depressants and modifiers, are selected for their effect on valuable mineral grade and recovery, while thickener performance is optimised separately through coagulant and flocculant dosing; the two chemistries are rarely considered together. Yet flotation tailings entering a thickener are not chemically inert; many depressants and modifiers are polymeric or ionic species that resemble the coagulants and flocculants used downstream, and could plausibly enhance, suppress or otherwise alter particle destabilisation and floc growth. This review synthesises literature on flotation reagent chemistry, coagulation-flocculation theory, and the factors (pH, ionic strength/valence, dosage, zeta potential and temperature) known to govern C-F-S performance in both tailings and general water-treatment systems, in order to evaluate the plausibility and evidence base for this coupling. Findings from the literature show consistent qualitative agreement between flotation-tailings and water-treatment systems for each factor, but almost no direct evidence on residual flotation reagents themselves, a gap now beginning to be addressed by recent studies on residual coagulants, flocculants and dewatering aids re-entering flotation circuits. The review concludes with a focused set of research priorities rather than a detailed experimental protocol, aimed at establishing whether, and under what conditions, flotation reagent selection should be treated as a dewatering-relevant decision.

Keywords: Flotation reagents; coagulation-flocculation-sedimentation; tailings dewatering; closed water circuits; dry stacking; thickening

1. Introduction

The sustainable management of water and tailings has become one of the most pressing challenges facing the global minerals processing industry. Froth flotation, the dominant beneficiation route for sulfide and many oxide ores, is inherently water intensive; flotation slurries typically comprise 65-80% water (Muzenda, 2010; Slatter et al., 2009). As water scarcity intensifies, particularly in mining regions such as Southern Africa, concentrators face increasing pressure to close or near-close their water circuits, reduce freshwater abstraction and minimise liquid effluent discharge (Harrison et al., 2018). Concurrently, tailings management is undergoing a fundamental reassessment following a series of high-profile tailings dam failures worldwide. This has accelerated a shift away from conventional wet tailings storage towards thickened, paste and filtered ("dry-stacked") tailings disposal (Fan et al., 2020; Yaghoobian et al., 2022). Central to all of these strategies is the effective dewatering of flotation tailings, both to maximise water recovery for reuse and to produce mechanically stable tailings with reduced environmental and safety risk. Existing reviews have addressed flotation reagent chemistry and tailings dewatering as separate

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literatures; what distinguishes the present review is that it explicitly juxtaposes the two, factor by factor, to test whether residual flotation reagents are plausibly relevant to downstream thickening, rather than treating flotation chemistry and dewatering chemistry as independent domains.

Tailings dewatering is achieved predominantly through coagulation-flocculation-sedimentation (C-F-S) in thickeners, often followed by filtration. The efficiency of C-F-S governs underflow density, settling rate, overflow clarity, and the quality of the reclaimed water returned to the concentrator (Bratby, 2016; Arjmand et al., 2019). While the roles of coagulants and flocculants in dewatering are well established in the water-treatment literature (Pearse, 2003), C-F-S is typically treated in concentrator design as a downstream, largely mechanical unit operation, decoupled from upstream flotation chemistry.

This decoupling is questionable because flotation tailings entering the thickener are not chemically inert. They carry residual collectors, frothers, depressants and modifiers, together with dissolved inorganic species, whose concentrations and speciation depend on ore mineralogy, reagent suite, operating conditions and the extent of water recycling (Muzinda and Schreithofer, 2018; Manenzhe et al., 2023). Several of these reagents, most notably polysaccharide and polyacrylamide-based depressants, are functionally similar to the polymeric flocculants used in thickening (Wiese et al., 2008; Parolis et al., 2008). It is therefore plausible, though not yet well evidenced, that residual flotation reagents influence the C-F-S behaviour of tailings, and conversely that residual dewatering reagents recycled into the flotation circuit influence flotation performance. Recent work has begun to test the latter directly (Manono et al., 2024a, 2024b, 2024c), confirming that the coupling is measurable, at least for the reverse direction of the interaction.

This paper synthesises the flotation reagent, coagulation-flocculation and tailings dewatering literature to evaluate the evidence for, and mechanistic plausibility of, this coupling. Rather than presenting new experimental data, it is positioned as a conceptual and integrative review, and its purpose is threefold: (i) to critically review the chemical nature of flotation reagents in relation to C-F-S mechanisms; (ii) to compare, factor by factor, the behaviour of flotation-tailings systems and general water-treatment systems under coagulation-flocculation, drawing out where the evidence is consistent and where it is absent; and (iii) to set out a focused research agenda for establishing whether, and to what extent, flotation reagent selection should be treated as a variable relevant to tailings dewatering performance and reclaimed water quality.

2. Problem statement and research gaps

Flotation reagents chemistry and tailings dewatering technology have, for the most part, evolved as separate fields. In most concentrator design and optimisation frameworks, flotation reagents are selected and evaluated almost exclusively on their impact on grade, recovery and froth behaviour, while dewatering performance is addressed downstream through the selection and optimisation of coagulants, flocculants and thickener operating conditions, largely independent of the reagent suite used upstream. Three interrelated gaps, summarised in Table 1, follow from this separation.

Table 1. Three interrelated gaps in linking flotation reagent chemistry and tailings dewatering technology.

Research gap	Current understanding	Key unresolved issue	Implications for flotation-tailings systems
Mechanistic understanding	Coagulation–flocculation mechanisms, including DLVO interactions, charge neutralisation and polymer bridging, are well established for water treatment systems (Gregory, 2006; Bratby, 2016).	Limited mechanistic understanding exists of how residual collectors, frothers and depressants modify particle–particle and polymer–particle interactions in flotation tailings.	Mechanisms established largely in synthetic or municipal wastewater systems may not adequately describe chemically complex flotation tailings.
Integration of flotation chemistry and dewatering performance	Laboratory thickening studies commonly evaluate settling and flocculation under controlled conditions.	Simplified or synthetic tailings often exclude the chemical memory imparted by upstream reagent dosing, recycled process water, and dissolved gangue species.	Laboratory-derived settling and dewatering behaviour may not translate directly to plant conditions.
Closed water circuits and dry stacking	Dewatering performance is commonly assessed through parameters such as settling rate, underflow density and overflow clarity.	The influence of residual flotation reagents on overflow water chemistry, dissolved organic content, floc structure and filterability remains insufficiently integrated with flotation performance (Manono et al., 2024a, 2024b).	Recycled-water quality may feed back into flotation performance, while changes in floc structure and filterability may affect achievable solids content and dry-stack stability.

The central research problem addressed by this review can therefore be stated as follows: how do residual flotation reagents plausibly influence the coagulation-flocculation-sedimentation behaviour of flotation tailings, and what does the existing evidence base, drawn from both tailings-specific and general water-treatment studies, suggest about the practical significance of this influence for reclaimed water quality, thickener performance and dry tailings disposal?

3. Literature review

3.1. Flotation reagents and particle interactions

Flotation reagents govern the interactions occurring in the pulp and froth zones of a flotation cell and therefore largely determine flotation performance (Napier-Munn and Wills, 2006). By the same token, these reagents and their residues are a plausible source of influence over the flocculation-coagulation-sedimentation behaviour of the resulting tailings, since many share functional groups (ionic, polymeric, surface-active) with dedicated coagulants and flocculants. Table 2 summarises the main classes of flotation reagents, their typical application and representative chemical examples (adapted from Bulatovic, 2007, 2014).

Reagent selection in each circuit depends on ore type, reagent availability and cost, expected metallurgical performance, and environmental, health and safety considerations. Flotation reagents are broadly classified as collectors, frothers, depressants and modifiers (which include activators and pH regulators), although these functions are not always mutually exclusive; some frothers exhibit collector-like behaviour and vice versa, and depressants and dispersants often have interchangeable functions (Martinovic et al., 2005; King, 1982).

3.2. The role of the collector in flotation and its interaction with particles

Collectors are organic compounds whose molecular structure comprises a non-polar (hydrocarbon) group and a polar group capable of dissociating in water (Bulatovic, 2007). During adsorption, the polar group orients towards the mineral surface and the non-polar group towards the aqueous phase, rendering the particle hydrophobic. Fig. 1 shows the structural formulae of xanthate and dithiophosphate (DTP) collectors, both anionic thiol collectors widely used in bulk sulfide flotation of platinum group mineral (PGM)-bearing ores (Martinovic et al., 2005).

Table 2. Summary of chemical reagents used in froth flotation, with typical examples (adapted from Bulatovic, 2007; 2014).

Reagent type	Function	Typical application	Chemical groups	Common examples
Collector	Renders target mineral surfaces hydrophobic	Sulfide minerals	Thiol compounds	Xanthates (e.g. SIBX), dithiophosphates (DTP), dithiocarbamates
		Oxide minerals	Carboxylates, amines	Fatty acids (oleic acid), fatty amines
		Non-polar minerals (e.g. talc, coal)	Hydrocarbon oils	Diesel, kerosene
Frother	Stabilises the froth phase and controls bubble size	Sulfide and oxide minerals	Alcohols, polyglycols, heterocyclics	Methyl isobutyl carbinol (MIBC), polypropylene glycol ethers, terpineol, pine oil
Depressant	Selectively renders gangue or unwanted sulfide surfaces hydrophilic	Sulfide and oxide minerals (e.g. talc, phyllosilicates, pyrite)	Polysaccharides, synthetic polymers	Carboxymethyl cellulose (CMC), guar gum, dextrin, polyacrylamide (PAM)
Activator	Promotes flotation of an otherwise poorly floating mineral	Sulfide minerals (e.g. sphalerite)	Metal ion salts	Copper sulfate
pH regulator (modifier)	Sets and maintains pulp pH for selective flotation	Sulfide and oxide minerals	Inorganic acids and alkalis	Lime (CaO), sodium hydroxide, sulfuric acid

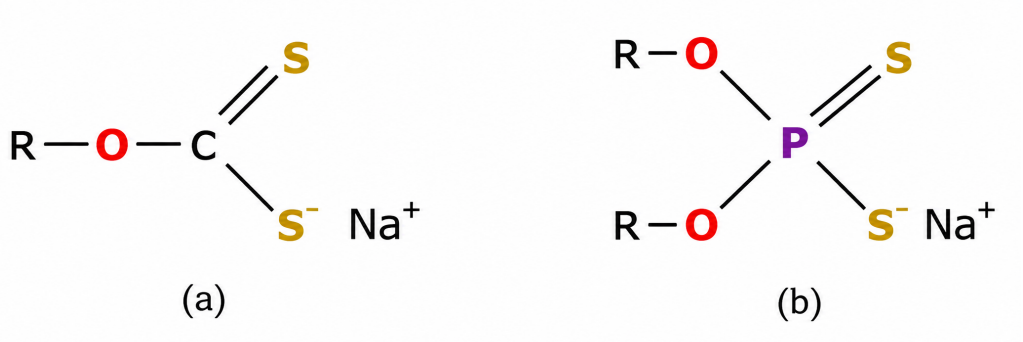

Fig. 1. Structural formulae of (**a**) xanthate and (**b**) dithiophosphate (DTP) collectors (redrawn after Martinovic et al., 2005).

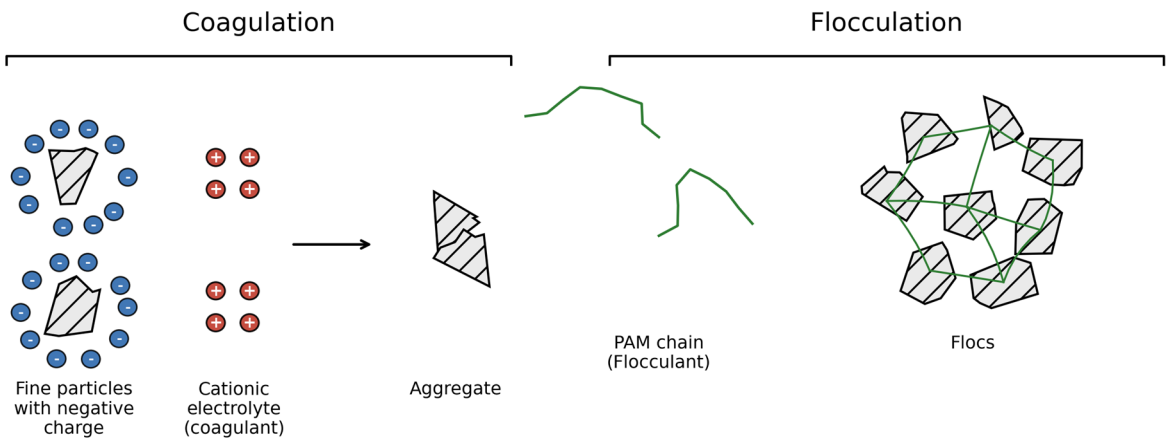

Fig. 2. Schematic illustration of the coagulation and flocculation of fine particles in a slimes mixture, in the presence of a cationic coagulant and a polyacrylamide flocculant (redrawn after Michaux et al., 2018).

The mechanism of mineral-collector bonding depends on collector type and mineral surface chemistry (Martinovic et al., 2005). Thiol collectors such as sodium isobutyl xanthate (SIBX) and DTP are favoured for their solubility and low sensitivity to the counter-cation (Taggart, 1945), and are used in neutral to slightly alkaline pulps, since strongly acidic conditions promote decomposition of xanthate to xanthic acid, carbon disulfide and an alcohol (Bulatovic, 2007). Dithiophosphates offer weaker collecting power than xanthates but better rejection of iron sulfides such as pyrite and pyrrhotite; DTPs are typically dosed as secondary collectors at higher pH (Bulatovic, 2007; Parekh, 1999; Veki, 2013). Because these residual collectors are anionic and surface-active, they represent one of the more plausible mechanistic links to downstream coagulation-flocculation behaviour.

3.3. Coagulation, flocculation and sedimentation: Definitions and mechanisms

Coagulation and flocculation are related, but mechanistically distinct processes, and the distinction matters for interpreting how residual flotation reagents might behave in a thickener. Coagulation refers to the destabilisation of colloidal particles through charge neutralisation, typically achieved using inorganic metal salts that dissociate into monovalent or multivalent cations (Bratby, 2016; Gregory, 2006). Flocculation, by contrast, uses polymeric reagents that both neutralise surface charge and physically bridge particles into larger, stronger aggregates (flocs), which settle more readily and produce a clearer supernatant (Bratby, 2016). In practice, the two are frequently combined, with a coagulant used to first destabilise fine colloids before a flocculant is added to grow settleable flocs. Fig. 2 illustrates this combined coagulation-flocculation process for a slimes mixture containing clay minerals, oxides, hydroxides and sulfide gangue.

Colloidal particles in suspension carry a surface charge - positive or negative, depending on the surface chemistry of the specific mineral and solution conditions (Gregory, 2006), which attracts a layer of oppositely charged ions, followed by a diffuse secondary ion layer, giving rise to the electric double layer (Bratby, 2016). The Derjaguin-Landau-Verwey-Overbeek (DLVO) theory explains particle stability as the balance between electrostatic double-layer repulsion and van der Waals attraction (Fig. 3). For agglomeration to occur, the energy barrier arising from double-layer repulsion must be reduced or eliminated, either by charge neutralisation (coagulation) or by polymer bridging (flocculation) (Gregory, 2006). Overdosing a coagulant or flocculant can reverse this effect; charge reversal or full polymer coverage of the particle surface can re-stabilise colloids, a phenomenon variously described as over-neutralisation or restabilisation (Bratby, 2016). Electrostatic repulsion forces are sensitive to the ionic composition and strength of the solution, while van der Waals attraction is governed by bulk material properties and surface roughness (Gregory, 2006).

The classical DLVO theory, while a useful first approximation, does not capture several interactions relevant to real mineral tailings suspensions. Extended DLVO (EDLVO) theory adds three further energy terms to the electrostatic and van der Waals components; a Lewis acid-base (AB) term capturing hydration and hydrophobic interactions at the particle surface, which can be strongly attractive for hydrophobic (e.g. partially floated or collector-coated) particles and strongly repulsive for hydrated hydrophilic surfaces (van Oss, 2006); a steric/hydration repulsion term arising from adsorbed polymer or hydration layers, which becomes significant once polymeric depressants or flocculants coat the particle surface at higher coverage; and a short-range Born repulsion term that prevents particle interpenetration at contact (Bournival et al., 2021). For flotation tailings specifically, the AB term is potentially significant because residual collectors leave mineral surfaces heterogeneously hydrophobic, so EDLVO, rather than classical DLVO, is the more appropriate framework for predicting how such surfaces will respond to a subsequently dosed coagulant or flocculant, particularly in saline or high-ionic-strength process water where the electrostatic term alone is strongly compressed (Bournival et al., 2021; Corin et al., 2011).

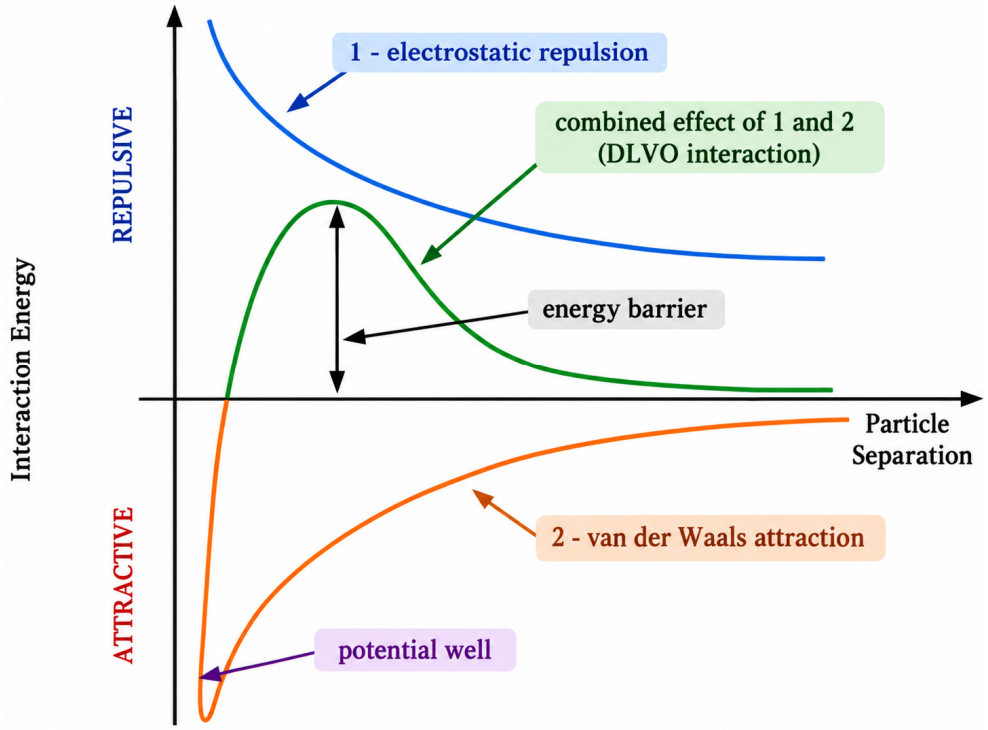

Fig. 3. Schematic illustration of the DLVO theory of colloidal stability (redrawn after Gregory, 2006).

The traditional industrial approach to dewatering fine particle suspensions therefore combines an inorganic coagulant, added to neutralise surface charge and form weak micro-flocs, with an organic flocculant, added to bridge these micro-flocs into larger, stronger, faster-settling flocs (Chong, 2012). An alternative, "direct flocculation" approach uses only a medium- to high-charge-density polymer, selected as cationic or anionic depending on the system (Lee et al., 2014). Direct flocculation produces more compact, bridged flocs, generates less sludge, and can be substantially cheaper than combined coagulation-flocculation, but it is largely restricted to organic wastewaters containing suspended impurities, which limits its applicability to the more mineralogically variable tailings streams that are the focus of this review (Chong, 2012). Table 3 compares these two distinct mechanisms.

Table 3. Comparison of coagulation-flocculation and direct flocculation (adapted from Chong, 2012).

Parameter	Coagulation-flocculation	Direct flocculation
Particle removal	Soluble solids and metals	Stabilised colloidal particles
Chemicals used	Metal salt coagulants plus flocculants	Flocculant only
Suitable feed	Inorganic, organic or potable water	Organic wastewater; requires high solids content
pH adjustment	Often required to counteract acidic environments	Not required (flocculants used are pH-neutral)
Sludge generation	Larger volumes, harder to dispose of	Smaller volumes, easier disposal (organic)
Process complexity	Higher (more reagents, more dosing points)	Lower (single reagent)
Relative cost	Higher	Approximately 3.6 times lower (Chong, 2012)

Within these two distinct mechanisms, three specific particle-particle interactions govern floc formation and strength (Sharma et al., 2006). These interactions contribute to the strength and size of the flocs formed, and hence the sedimentation that follows. The first observable example of this is charge neutralisation (Fig. 4(a)). This is the chemical reaction of particles of opposite charge resulting in neutral particles. These particles then experience attraction via van der Waals forces. The important consideration in this interaction is ensuring that the polyelectrolyte dewatering or clarification agent added creates the appropriate zeta potential (Sharma et al., 2006). Zeta potential is the difference in potential between the solid particle and the liquid. In this instance, a decrease in zeta

potential is indicative of a reduction in electrostatic repulsion, an essential consequence of this interaction.

The second type is that of polymer bridging, exclusive to flocculants. Current research has shown this to be the driving force for particle settling in cases of high molecular weights with low to medium charge density. Once the polymer has been added into solution, segments begin to adsorb onto particles. The flocculant would still have extended segments that exist in solution. These extended segments of the flocculant begin to adsorb onto other free particles, resulting in the formation of a chain. The polymer adsorbs in two manners: either as loops or trains on the surface (Lee et al., 2014). This can be seen in Fig. 4 (b). This requires the polymer chain to extend beyond the particle surface, as well as the availability of other particles to be attached. A counteracting force in this interaction would be the addition of excess polymer. This would result in the particles being stabilised through repulsive forces, as seen in Fig. 4 (c).

The last interaction, illustrated in Fig. 5, is known as the electrostatic patch. This is often seen in cases in which a highly cationic flocculant is used. This is a specialised form of charge neutralisation in which the negative charges of colloids are counteracted. However, it is not possible for the entire particle to become completely neutral, hence the formation of positive and negative 'patches'. This would lead to the attraction between particles, although the flocs formed are weaker in comparison to polymer bridging (Sharma et al., 2006). It is important to note that such interactions can also take place between the solid particles and inorganic ions (coagulants).

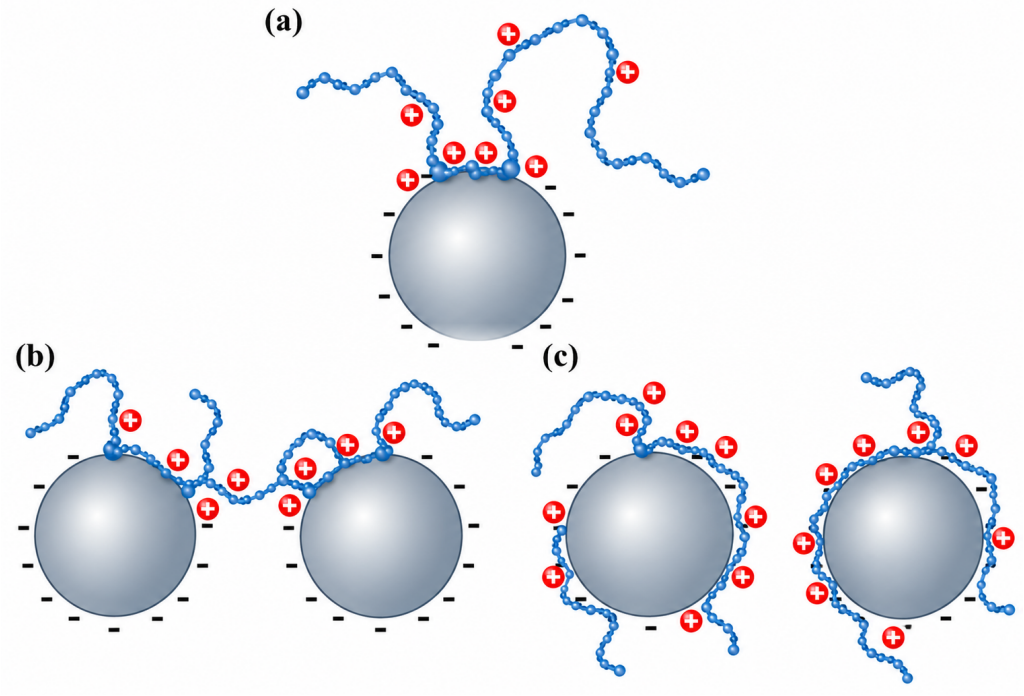

Fig. 4. (**a**) Adsorption of polymer and formation of loops available for binding. (**b**) Polymer bridging between particles (agglomeration). (**c**) Re-stabilisation of colloid particles (floc breakup) (adapted from Sharma et al., 2006).

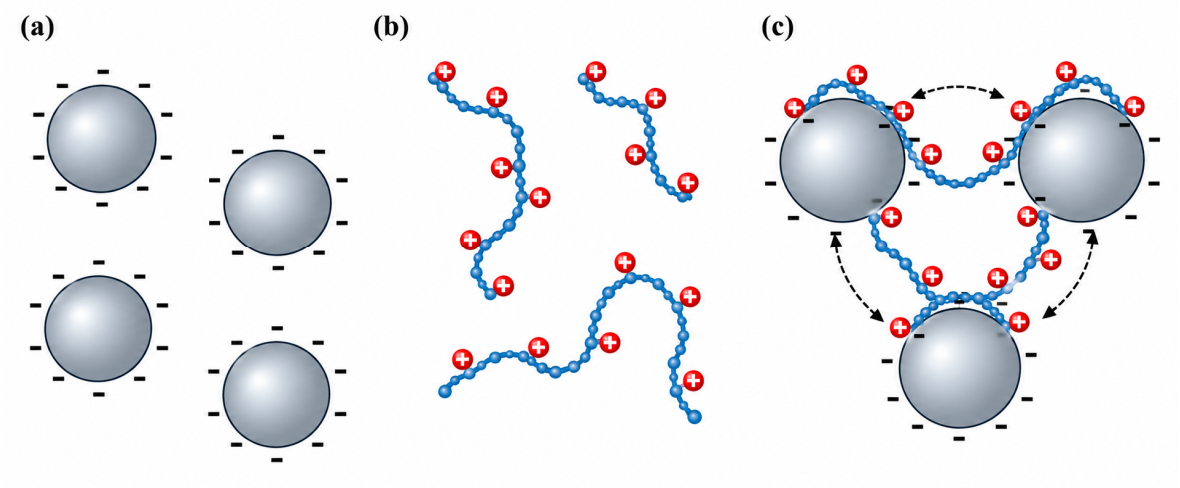

Fig. 5. (**a**) Negatively charged particles; (**b**) Cationic flocculants; (**c**) Charge neutralisation flocculation by patch mechanism. Arrows in (**c**) show attraction of opposite charges (adapted from Sharma et al., 2006).

It is worth mentioning that these same three interactions can, in principle, occur between tailings particles and inorganic ions or residual organic reagents carried over from flotation.

3.4. Chemical reagents used for coagulation, flocculation and sedimentation in dewatering

Given the physicochemical interactions taking place in thickeners and clarifiers, a range of chemical reagents is used to effect the necessary coagulation-flocculation-sedimentation of solid particles and achieve the desired underflow density and overflow clarity (Bratby, 2016). This section reviews the main classes of dewatering reagents and compares them to the flotation reagents already discussed, since this comparison underpins the arguments developed later in this review.

The functional analogy drawn above between flotation depressants and dewatering flocculants should not be overstated, the two reagent classes differ substantially in scale. Polymeric flotation depressants such as carboxymethyl cellulose and guar gum typically have molecular weights in the tens to low hundreds of kDa and are dosed at 10-100 g/t of ore (Bulatovic, 2007; Mackenzie et al., 1986), giving residual concentrations in thickener feed on the order of single-digit mg/L once diluted by process water. Conventional flocculants, by contrast, are typically high-molecular-weight polyacrylamides of several to over ten million Da, dosed at 5-50 g/t of solids directly into the thickener feedwell (Bratby, 2016), and their much higher molecular weight and chain length give them a markedly greater bridging capacity per unit mass than a depressant of similar dosage. Charge density also differs; flotation depressants are typically weakly anionic or non-ionic to avoid excessive mineral surface coverage, whereas dewatering flocculants are selected across a wide ionicity range (typically 10-40 mol% charged monomer) specifically to maximise destabilisation (Morris et al., 2002; Wang, 2016). The plausibility of the coupling explored in this review therefore rests on residual depressant carryover acting as a low-dose, low-charge-density flocculant analogue, not as a direct substitute for deliberate flocculant dosing.

3.4.1 Inorganic Coagulants

Inorganic coagulants used in tailings and wastewater dewatering are salts, commonly aluminium chloride, ferric chloride and lime, that dissociate into ions whose primary function is charge neutralisation (Bratby, 2016; Gregory, 2006). Their main drawbacks are the production of metal hydroxide sludge, which is difficult and costly to dispose of responsibly; the health and environmental risk posed by residual metal ions in the treated water (Lee et al., 2014); and strong pH sensitivity, which may require additional reagents to correct pH after dosing (Manono, 2018). Relative to flocculants, coagulants must be dosed at higher concentrations and are less effective at removing fine colloids from suspension (Bratby, 2016). This has driven growing interest in direct flocculation and eco-friendly alternatives (Lee et al., 2014).

3.4.2 Flocculants

Flocculants are conventionally divided into three categories, namely, organic synthetic polymers, bio-flocculants, and grafted (semi-synthetic) polymers.

Organic synthetic flocculants refer to synthetic polymers such as polyacrylamide (PAM) and polyamines. These are highly efficient at low dosage, are instantly soluble, and can remove up to 90% of suspended solids without requiring pH adjustment (Lee et al., 2014; Gregory, 2006). Their principal disadvantage is poor biodegradability. Because these are largely petrochemical-derived, residual monomer in the treated water can pose serious health risks (Bratby, 2016). Synthetic flocculants may be cationic, anionic, amphoteric, or non-ionic (polyelectrolytes), and the appropriate charge type depends on the colloid system being treated.

Beyond charge type, three flocculant properties govern tailings flocculation performance and are frequently varied in practice. Molecular weight determines bridging span and floc strength. Higher-molecular-weight polyacrylamides (several to over ten million Da) form larger, faster-settling flocs at low dosage, but excessive molecular weight can produce flocs too fragile to withstand the shear encountered in thickener rake mechanisms, reducing dewaterability despite a larger initial floc size (Addai-Mensah et al., 2007). Molecular architecture and branching structure affect this trade-off directly; linear high-molecular-weight polymers maximise bridging span and are generally preferred for coarse, fast-settling tailings, whereas branched or crosslinked structures produce more compact, shear-resistant flocs better suited to fine, slow-settling fractions, at some cost in maximum floc size (Fan et al., 2020). Charge density (ionicity), typically expressed as the mole fraction of charged monomer, must be matched to the surface charge density of the tailings particles. Under-dosing relative to particle charge favours bridging flocculation, while charge densities approaching or exceeding the particle demand shift the mechanism towards charge neutralisation and risk restabilisation at overdose. Because tailings mineralogy and particle-size distribution vary substantially between ore types, these three properties, rather than flocculant dosage alone, are the primary levers for optimising C-F-S performance for a given tailings stream.

Bio-flocculants have been developed as eco-friendly alternatives to synthetic polymers, and are conventionally described as polysaccharide-based (e.g. chitosan, guar gum, starch, tannins, cellulose derivatives), functioning through hydroxyl and carboxyl groups that neutralise colloid charge and reduce the zeta potential to promote agglomeration (Sharma et al., 2006). More recent work, however, has shown that many microbially produced bio-flocculants are in fact glycoproteins, with protein contents in some cases exceeding 25% by mass and contributing significantly to flocculating activity through amine and carboxyl functional groups (Nie et al., 2023; Zhao et al., 2020). Plant-protein-based coagulant-flocculants, such as those derived from *Moringa oleifera* seed protein, have also shown strong performance in organic matter and pathogen removal from wastewater (Nonfodji et al., 2020). Compared with synthetic flocculants, bio-flocculants generally produce a supernatant of lower clarity (in terms of turbidity, total suspended solids (TSS), and total dissolved solids (TDS)) and require higher dosages but generate biodegradable sludge that is more easily and

safely disposed of (Zhao et al., 2020; Nazari et al., 2023).

Grafted or semi-synthetic polymers combine a natural (bio-based) backbone with synthetic polymer side-chains, aiming to retain some of the biodegradability advantages of bio-flocculants while achieving the lower effective dosages and longer shelf-life of synthetic flocculants (Lee et al., 2014). Their performance depends on the molecular architecture of the graft, and their manufacture is presently either costly or not fully environmentally benign, which has limited their industrial uptake relative to conventional synthetic flocculants (Zhao et al., 2020). Fig. 6 summarises the coagulant and flocculant families discussed.

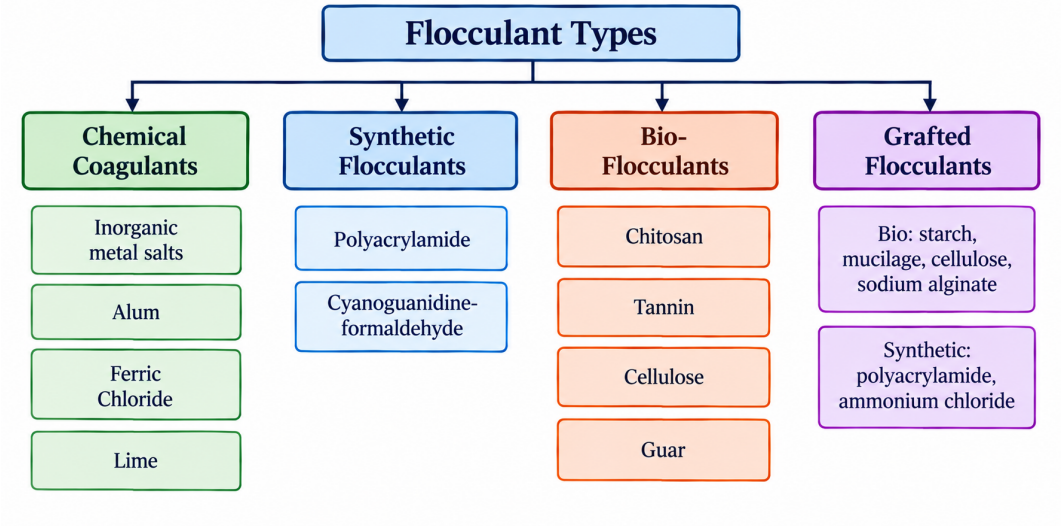

Fig. 6. Summary of coagulant and flocculant types used in mine tailings dewatering and wastewater treatment (redrawn and adapted after Bratby, 2016 and Lee et al., 2014).

3.5 Laboratory techniques for studying coagulation-flocculation-sedimentation

A relatively small set of standardised laboratory techniques underpins most of the literature reviewed, and is summarised here for completeness.

- The jar test simulates full-scale coagulation-flocculation at bench scale using a digital flocculator, recording turbidity, temperature and pH as a function of agitation and settling time (Bratby, 2016).
- Sedimentation yield (Eq. 1) quantifies the mass fraction of solids settled after a fixed settling period, and is commonly used for tailings such as those of muscovite (Tang et al., 2016):

$$D = [m_{sed}/(m_{susp} + m_{sed})] \times 100\% \quad (1)$$

where D is the sedimentation yield, m_{sed} is the mass of settled sediment, and m_{susp} is the mass of the remaining suspension.

- Settling rate is calculated from the change in interface height over time in a graduated cylinder (Gungoren et al., 2020).
- Turbidity quantifies the loss of water transparency caused by suspended particles, measured optically, and is commonly reported as a percentage removal relative to the initial (unflocculated) reading (Bratby, 2016).
- Zeta potential measures the electrical potential at the shear plane between a particle and the surrounding fluid; its magnitude (irrespective of sign) indicates the degree of electrostatic repulsion between particles, and is measured using electrophoretic light scattering (a "zeta meter") (Gregory, 2006).
- Laboratory batch flotation remains the standard method for evaluating flotation reagent performance on representative ore samples (Napier-Munn and Wills, 2006; Bernardis and Wallenius, 2018), but conventional batch flotation testwork does not extend to characterising the downstream dewatering behaviour of the resultant tailings; a methodological gap this review seeks to highlight.

Table 4 summarises the laboratory methods used by the key studies discussed in this paper.

Table 4. Laboratory methods used in the key studies reviewed.

Study	System	Jar test	Batch flotation	Zeta potential
Gungoren et al. (2020)	Coal tailings	✓	-	-
Tang et al. (2016)	Muscovite tailings	✓	-	✓
Zhai et al. (2019)	Tungsten tailings	✓	✓	✓
Ma et al. (2019)	Potable water	✓	-	✓
Arjmand et al. (2019)	Iron ore tailings	✓	-	-
Nguyen et al. (2007)	Activated sludge	✓	-	-
Li et al. (2020)	Potato starch wastewater	✓	-	✓

4. Factors influencing coagulation-flocculation-sedimentation: A comparative synthesis

This section synthesises recent studies on the factors known to govern C-F-S performance, drawing in parallel on (i) studies conducted directly on flotation tailings (coal, iron ore, muscovite and tungsten-molybdenum tailings) and (ii) studies from the broader water and wastewater-treatment literature (potable water, activated sludge and starch-processing wastewater). The comparison is organised by factors such as pH, ionic concentration/valence, flocculant dosage, zeta potential (particle charge) and temperature rather than by system, so that consistencies and gaps between the two literatures are easier to identify. Table 5 summarises this comparative synthesis between C-F-S in flotation tailings systems and water/wastewater treatment systems.

Table 5. Comparative summary of the effect of key factors on coagulation-flocculation-sedimentation performance in flotation-tailings systems and general water/wastewater-treatment systems.

Factor	Flotation-tailings systems	Water/wastewater-treatment systems	Consistency across systems
pH	Muscovite: sedimentation yield highest under strongly acidic or, with Ca^{2+}/Mg^{2+} present, moderately alkaline conditions, with an inflection near pH 4 (Tang et al., 2016). Iron tailings: settling rate and turbidity removal both improved under alkaline conditions (Arjmand et al., 2019).	Potable water treatment: optimum removal of turbidity and colour at near-neutral pH 6-8, degrading under both strongly acidic and strongly alkaline conditions (Ma et al., 2019). Potato starch wastewater: removal rate increased with increasing (more alkaline) pH (Li et al., 2020).	Each system shows a distinct, chemistry-specific optimum pH range, but pH is consistently identified as a first-order control variable across both literatures.
Ionic concentration/valence	Coal tailings: divalent ions (Mg^{2+}, Ca^{2+}) are more effective than monovalent ions (Na^{+}, K^{+}) at low concentration (~10^{-2} mol/L), reversing at high concentration (1 mol/L) where monovalent ions became more effective, consistent with over-neutralisation of colloids by divalent species (Gungoren et al., 2020). Muscovite: increasing Ca^{2+}/Mg^{2+} concentration increased sedimentation yield under alkaline conditions (Tang et al., 2016).	Activated sludge: higher calcium concentration produced faster floc formation and a higher steady-state flocculation index (Nguyen et al., 2007).	Ionic strength and valence consistently affect flocculation performance in both literatures, with divalent species generally more effective at low concentration in line with DLVO/Schulze-Hardy expectations, but prone to over-neutralisation at high concentration.
Flocculant dosage	Coal tailings: an optimum dosage produced the largest, most settleable flocs; dosages either side of the optimum increased turbidity (Gungoren et al., 2020). Tungsten tailings: increasing dosage steadily improved interface height and turbidity up to a plateau (Zhai et al., 2019). Iron tailings: dosage increased in proportion to floc growth rate, with over-dosing causing re-suspension of settled particles (Arjmand et al., 2019).	Potable water: an optimum dosage (~40 mg/L) achieved near-complete colour and turbidity removal, with both under- and over-dosing reducing performance to ~75% (Ma et al., 2019). Potato starch wastewater: removal rate peaked near zero zeta potential, with over-dosing causing charge reversal and re-stabilisation (Li et al., 2020). Activated sludge: capillary suction time improved monotonically with dosage over the tested range (Nguyen et al., 2007).	An optimum-dosage response, bounded by under-flocculation on one side and re-stabilisation/re-suspension on the other, is the dominant pattern across both literatures.
Zeta potential	In muscovite and tungsten tailings: zeta potential decreased towards zero with increasing coagulant/flocculant addition, correlating with improved settling and reduced turbidity (Tang et al., 2016; Zhai et al., 2019).	Potable water and starch wastewater: cationic flocculants (e.g., cPAM) reduced the magnitude of negative zeta potential or reversed its sign; optimal removal coincided with zeta potential close to zero (Ma et al., 2019; Li et al., 2020).	Strongly consistent: minimising the absolute zeta potential (rather than simply adding more reagent) is the common mechanistic target in both literatures.
Temperature	Not separately isolated in the flotation-tailings studies reviewed.	Potable water treatment: turbidity/colour removal was only weakly sensitive to temperature over -5 to 30 °C (91-98% removal across the range) (Ma et al., 2019).	Limited direct evidence for tailings systems; the water-treatment evidence suggests temperature is a second-order factor relative to pH, ionic strength, and dosage.

4.1 pH

Across both flotation tailings systems and water/wastewater treatment systems, pH consistently emerges as a first-order control on C-F-S performance, though the position of the optimum is system-specific rather than universal. In tailings systems, the effect operates largely through pH-dependent surface charge and ion speciation: for muscovite, sedimentation yield in the absence of added ions was highest under acidic conditions, while in the presence of Ca^{2+} or Mg^{2+} the response became non-monotonic, with an inflection near pH 4 that reflects the onset of hydroxo-complex formation and adsorption (Tang et al., 2016). For iron tailings flocculated with an anionic polyacrylamide, alkaline conditions instead favoured performance, attributed to greater uncoiling (and hence greater bridging reach) of the anionic flocculant chain under alkaline conditions (Arjmand et al., 2019). The water-treatment literature shows an analogous, system-specific optimum: potable-water treatment with a polysilicate-aluminium-magnesium/cationic-polyacrylamide dual system performed best near neutral pH, with both acidic and strongly alkaline extremes disrupting the cationic flocculant's structure or its electrostatic interaction with colloids (Ma et al., 2019).

For the specific case of flotation tailings, residual collectors (e.g., xanthates, which behave as weak bases) and frothers (e.g., alcohols, which behave as weak acids) are present at concentrations too low to meaningfully shift bulk slurry pH; pH in the thickener feed is instead governed principally by the gangue mineralogy and any residual pH modifiers (Corin and Wiese, 2014). This suggests that, while pH remains a first-order lever for thickener operators, its optimum for a given tailings stream should be established empirically for that ore rather than assumed from generic water-treatment literature.

4.2 Ionic concentration and valence

Ionic strength and valence affect C-F-S performance in a broadly consistent way across both flotation tailings systems and water/wastewater treatment systems, and the pattern is well explained by classical colloid theory. In coal tailings, divalent cations (Mg^{2+}, Ca^{2+}) outperformed monovalent cations (Na^{+}, K^{+}) at low ionic concentration (~10^{-2} mol/L), consistent with the higher charge-neutralising efficiency of divalent ions predicted by DLVO/Schulze-Hardy behaviour, but this reversed at high concentration (1 mol/L), where monovalent ions became more effective, most plausibly because excess divalent ion adsorption over-neutralised and re-charged the particle surface (Gungoren et al., 2020). A qualitatively similar increase in flocculation index with increasing calcium concentration was observed for activated sludge in wastewater treatment (Nguyen et al., 2007), and increasing Ca^{2+}/Mg^{2+} concentration likewise increased sedimentation yield for muscovite under favourable pH conditions (Tang et al., 2016).

Because the flotation-tailings experiments reviewed here used laboratory-prepared, single-salt systems rather than plant water carrying a full suite of residual flotation reagents, the extent to which this trend holds under industrially recycled water where ionic strength, residual reagent concentration and pH co-vary remains an open, empirically testable question rather than an established finding.

4.3 Flocculant dosage

Flocculant dosage shows the most consistent pattern of all the factors reviewed; an optimum-dosage response bounded by under-flocculation (small, fragile flocs; poor turbidity removal) at low dosage and re-stabilisation or re-suspension at high dosage, observed in coal tailings (Gungoren et al., 2020), iron tailings (Arjmand et al., 2019), potable water (Ma et al., 2019) and potato-starch wastewater (Li et al., 2020). For tungsten-molybdenum tailings, interface height and turbidity improved monotonically with dosage up to a plateau, without a clear overdosing penalty within the tested range, and turbidity in the absence of any flocculant remained relatively low, indicating that the small quantity of residual flotation reagent present in this particular tailings stream was insufficient to measurably influence baseline turbidity (Zhai et al., 2019). This is the closest direct (if indirect) evidence in the reviewed literature that, at typical residual concentrations, flotation reagent carryover into a thickener may in some cases be too dilute to materially affect dosage requirements, though this cannot be generalised without dedicated testing across a wider range of ore types and reagent suites.

4.4 Zeta potential

Zeta potential provides the clearest unifying mechanistic thread across the reviewed literature; in every system considered, optimal C-F-S performance coincided with the absolute zeta potential being driven towards zero, whether by coagulant/flocculant charge neutralisation (muscovite and tungsten tailings; Tang et al., 2016; Zhai et al., 2019) or by cationic polymer addition (potable water and starch wastewater; Ma et al., 2019; Li et al., 2020). This is consistent with DLVO theory, in which the energy barrier to agglomeration is minimised as the electrostatic double-layer repulsion term approaches zero (Gregory, 2006). Practically, this means zeta-potential measurement is a more direct and system-independent diagnostic of C-F-S readiness than pH, ionic strength or dosage considered individually, and its use in monitoring thickener feed chemistry - including any drift caused by changing flotation reagent suites - merits greater attention in plant practice.

4.5 Temperature

Temperature was not isolated as an independent variable in the flotation-tailings studies reviewed, representing a further, specific gap. In the water-treatment literature, potable-water flocculation performance was only weakly sensitive to temperature between -5 and 30 °C (91-98% turbidity and colour removal across this range) (Ma et al., 2019), suggesting that temperature is likely a second-order factor relative to pH, ionic strength and dosage for most tailings systems, though this has not been directly verified for flotation tailings and should not be assumed without site-specific confirmation, particularly for operations with strongly seasonal process-water temperature variation.

4.6 Particle size and mineralogical composition

Particle size distribution and mineralogical composition of tailings are major, and often confounding, sources of variability in C-F-S performance, independent of any reagent effect. Finer particle-size fractions present substantially greater specific surface area per unit mass, increasing both the reagent dosage required for effective coverage and the susceptibility of the suspension to restabilisation, while coarser fractions settle predominantly under gravity with comparatively little sensitivity to flocculant chemistry (Johansson and Pugh, 1992; Peng and Seaman, 2011). This has practical implications for the coupling explored in this review: a flotation-tailings stream dominated by fine, slow-settling slimes would be expected to show a stronger, more readily detectable response to residual reagent carryover than a coarser stream, simply because a larger fraction of the surface area available for reagent adsorption is unaccounted for. Mineralogical composition compounds this effect, since different gangue minerals (e.g., phyllosilicates such as talc and muscovite versus more inert quartz or feldspar) carry substantially different native surface charge and hydrophobicity, and therefore respond differently to a given coagulant/flocculant dose even at identical particle size (Arnold and Aplan, 1986; Becker et al., 2009; Vasudevan et al., 2012). Because flotation reagent suites are themselves selected according to ore mineralogy and particle size distribution; mineralogy and particle size distribution are plausible confounders that any future experimental test of the flotation-C-F-S coupling would need to control for or report explicitly.

4.7 Synthesis of findings

Considered together, it is evident that the mechanisms governing C-F-S - charge neutralisation, polymer bridging, and the DLVO energy balance behave consistently across both flotation-tailings and general water-treatment systems, even though the specific optimum for each factor is system-dependent. This consistency supports the mechanistic plausibility of the central hypothesis of this review; that residual flotation reagents, many of which are ionic or polymeric species with the same functional characteristics as dedicated coagulants and flocculants, are capable in principle of measurably shifting thickener performance. What the reviewed literature does not provide is direct evidence, from real (rather than laboratory-prepared) flotation tailings carrying a realistic residual reagent suite, of the magnitude of this effect, which is the specific gap identified in this study.

5. Considering flotation reagents in the dewatering of flotation tailings

The coupling proposed in this review follows a four-step pathway. (1) During flotation, collectors, frothers, depressants and pH modifiers are dosed to the pulp, and a fraction remains unadsorbed or weakly bound, reporting to the tailings stream together with dissolved gangue species mobilised during grinding and flotation. (2) These residual species, together with process water recycled from the thickener overflow, enter the thickener feed alongside the deliberately dosed coagulant/flocculant. (3) Where a residual reagent is surface-active, ionic or polymeric, it can adsorb onto tailings particle surfaces or interact with the added coagulant/flocculant, altering the electrostatic and steric interactions that govern particle aggregation; either reinforcing, competing with, or otherwise modifying the intended C-F-S mechanism. (4) The resulting change in floc size, structure and settling behaviour affects underflow density, overflow clarity and reclaimed-water quality, which in turn feeds back into flotation performance when that water is recycled (Manono et al., 2024a, 2024b, 2024c). This pathway is conceptual rather than quantitatively parameterised at any step.

Dewatering unit operations are set to play an increasingly critical role in mineral processing given the growing scarcity of water affecting countries such as South Africa. An optimised dewatering process in terms of reagent effects, sedimentation residence time and rate, and the quality of the water recovered would materially reduce the fresh feed water required for froth flotation.

As established in the literature, several classes of flotation reagents, particularly polysaccharide and polyacrylamide-based depressants share functional similarities with the polymers used as flocculants in thickeners (Wiese et al., 2008; Parolis et al., 2008), and the factors that govern C-F-S performance (pH, ionic strength, dosage, zeta potential) behave consistently whether the system is a flotation tailings stream or a general water-treatment stream. This supports the working hypothesis that coagulation-flocculation-sedimentation in a tailings thickener can, in principle, be affected by residual reagents carried over from froth flotation, because these reagents can interact with mineral particle surfaces in a manner analogous to purpose-dosed coagulants and flocculants or can affect the efficacy of purpose-dosed coagulants and flocculants. It is important to be explicit about the evidentiary basis of this hypothesis; for collectors specifically, the case rests on theoretical extension of DLVO/EDLVO surface-interaction principles and on structural analogy with known coagulant/flocculant chemistries, rather than on direct experimental measurement of collector carryover effects on C-F-S. Where direct experimental evidence exists at all, it concerns residual dewatering reagents affecting flotation, not the reverse; the collector-to-C-F-S direction of the coupling proposed here therefore remains a theoretically motivated hypothesis pending direct testing.

There is, however, a reasonable counter-hypothesis because residual flotation reagent concentrations in tailings are typically small relative to the dosages of coagulant and flocculant deliberately added at the thickener, their net effect on pH, ionic strength, and floc-forming capacity may be negligible in many circuits. The tungsten-molybdenum tailings data discussed earlier, where turbidity in the absence of added flocculant was already relatively low, is consistent with this counter-hypothesis for that particular system (Zhai et al., 2019), though it cannot be generalised.

This counter-hypothesis can be evaluated only approximately, because the literature does not yet report residual flotation-reagent concentrations in thickener feed directly. Indicative figures can nonetheless be assembled from typical plant dosing practice; collectors are commonly dosed at 10-100 g/t of ore (giving thickener-feed concentrations on the order of 0.1-1 mg/L once diluted

into a pulp of 30-40% solids), frothers at 10-50 g/t (similarly ~0.1-0.5 mg/L residual), and depressants at 10-200 g/t (~0.1-2 mg/L residual), while lime addition for pH control can contribute tens to a few hundred mg/L of Ca^{2+} depending on dosage and water hardness (Bulatovic, 2007; Wills and Finch, 2016). These residual concentrations are one to two orders of magnitude lower than typical deliberate coagulant dosing (50-500 mg/L for metal-salt coagulants) but are broadly comparable to, or in the case of Ca^{2+} can exceed, typical flocculant dosing (0.1-5 mg/L as product) (Bratby, 2016). On this basis, the dilution counter-hypothesis is plausible for collector and frother carryover, but less clearly so for depressant carryover or for lime-derived Ca^{2+}, both of which could plausibly reach concentrations comparable to deliberate dosing under high-water-recycle conditions. This estimate is necessarily approximate and is offered to motivate, rather than substitute for, the direct measurement recommended later in this study.

Direct evidence bearing on this question has begun to emerge only recently, and largely in the *reverse* direction, the effect of residual dewatering reagents recycled into flotation, rather than the effect of residual flotation reagents on dewatering. Working with a Cu-Ni-PGM Merensky ore, Manono et al. (2024b) showed that residual coagulant (an acrylamide-acrylate copolymer) and flocculant (a polyhydroxyalkylene dimethylammonium chloride) carried in recycled process water measurably increased froth stability and mineral recovery, with the acrylamide-acrylate copolymer showing the strongest effect; this effect could be substantially offset in the presence of a polyquaternary amine and carboxymethyl cellulose. In a companion study on a siliceous Merensky reef ore, Manono et al. (2024a) further showed that residual dewatering aids in recycled process water not only altered flotation recoveries and grades but also measurably affected the subsequent sedimentation behaviour of the resulting tailings - direct evidence that the flotation-dewatering coupling proposed in this review operates as a two-way feedback loop rather than a one-directional effect. These findings, published after the initial conception of this review, are, to the authors' knowledge, the first to measure this coupling directly, and they motivate the complementary question addressed by this review; whether flotation reagents themselves, carried forward into the thickener, produce an analogous effect on C-F-S performance. It should be noted that this direct evidence currently derives from a single research group working with a single ore type (a Cu-Ni-PGM ore from a siliceous Merensky reef), so its generality across ore types, reagent suites and water chemistries remains to be established. Independent supporting evidence is more indirect; studies on residual dispersant and polymer carryover in seawater tailings flocculation (e.g. work from the University of Antofagasta on copper tailings) point to comparable reagent-carryover effects in an adjacent system, but do not themselves address flotation reagent carryover into C-F-S.

A small number of further studies offer indirect but relevant case evidence. Ramos et al. (2013) showed that copper-molybdenite ore flotation in seawater is strongly affected by the elevated ionic strength and divalent cation content of seawater, mirroring the ionic-strength dependence identified for C-F-S and suggesting that any residual-reagent effect on C-F-S would itself be modulated by process water salinity. Ikumapayi et al. (2012) and Ikumapayi et al. (2010) examined the recycling of process water in sulfide flotation and found that accumulated calcium, sulfate and residual reagent species measurably altered flotation performance across recycle loops, which is consistent with, though again not direct evidence for, the reverse-direction feedback pathway described in this review (step 4, above). Taken together, these studies indicate that the building blocks of the proposed coupling (ionic-strength sensitivity, water-quality accumulation under recycling) are individually well evidenced, even though no published study has yet measured flotation reagent carryover and thickener C-F-S performance within the same experimental system. Table 6 summarises the studies most relevant to these gaps, the systems each investigated, their major findings, and the specific limitation that leaves the central research problem unresolved.

Table 6. Summary of the key studies underpinning the proposed flotation-C-F-S coupling, the systems they investigated, their major findings, and the limitations that motivate future research priorities.

System investigated	Major finding	Remaining limitation
Sulfide (Cu-Ni-PGM) ore, siliceous Merensky reef (Manono et al., 2024a, 2024b, 2024c)	Residual dewatering aids/coagulants recycled into flotation measurably alter recovery, grade and subsequent tailings settling behaviour.	Single ore type, single research group; reverse direction only (dewatering reagents -> flotation), not flotation reagents -> C-F-S.
Tungsten and muscovite tailings (Tang et al., 2016; Zhai et al., 2019)	Zeta potential magnitude, not reagent dosage alone, is the consistent driver of settling/turbidity improvement.	Synthetic/model tailings systems; no residual flotation reagent present.
Copper-molybdenite ore flotation in seawater (Ramos et al., 2013)	Elevated ionic strength and divalent cations strongly affect flotation performance.	Addresses flotation performance, not downstream C-F-S of the resulting tailings.
Recycled process water in sulfide flotation (Ikumapayi et al., 2012; 2010)	Accumulated Ca^{2+}, sulfate and residual reagents across recycle loops measurably alter flotation performance.	Addresses flotation performance under recycling, not C-F-S performance of tailings produced.
General water-treatment/coagulation-flocculation literature (Bratby, 2016; Gregory, 2006)	pH, ionic strength, dosage, and zeta potential govern C-F-S consistently across systems.	Systems are municipal/industrial wastewater, not flotation tailings carrying residual flotation reagents.

Confirming this would have direct implications for reclaimed water quality and, by extension, for the design of closed water circuits and the safe dry stacking of tailings; residual reagents that alter floc structure, permeability or filterability could compromise the solids concentrations required for filtered or dry-stacked tailings and increase energy or reagent demand at the thickener and filter. Conversely, ruling out a significant effect for a given ore-reagent system would allow flotation reagent selection and dewatering reagent selection to continue to be optimised independently for that system, without loss of process performance.

6. Recommended framework for future research

Rather than proposing a detailed experimental protocol, this review identifies four priorities that follow directly from the gaps identified in this paper, together with the expected direction of effect implied by the mechanistic evidence reviewed.

1. Establish the direct effect of residual flotation reagents on C-F-S performance, using real flotation tailings generated under a controlled reagent suite (rather than synthetic or single-salt systems), with C-F-S performance benchmarked using the standard metrics summarised in Table 5 (sedimentation yield, settling rate, turbidity removal and zeta potential). Based on the functional similarity between polymeric depressants and flocculants established in this paper, and the consistent zeta-potential mechanism identified in this paper, it would be expected that residual anionic depressants would behave qualitatively like a low-dose anionic flocculant - producing a measurable, if likely modest, shift in zeta potential and settling rate relative to depressant-free tailings; though the magnitude should be established experimentally rather than assumed. As a concrete starting point, depressant carryover should be tested across the 0-50 g/t range typical of plant dosing, alongside a conventional flocculant dose-response series (0-20 g/t) run under identical conditions, so the two dose-response curves can be compared directly.
2. Characterise reclaimed water quality (pH, electrical conductivity, TSS, TDS, key inorganic electrolytes such as Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-}, SO_4^{2-} and NO_3^{-}, and residual collector/depressant concentration) across successive water-recycle loops, to determine whether residual reagents and their dewatering by-products accumulate to concentrations capable of feeding back into flotation performance, in the manner already demonstrated for residual dewatering reagents by Manono et al. (2024a, 2024b).
3. Link dewatering performance to filterability and dry-stacking outcomes, by extending C-F-S testwork to include underflow specific gravity, viscosity, and filtration rate, since these rather than settling rate alone; and determine whether a given tailings stream can practically achieve the solids concentration required for dry stacking.
4. Develop ore-specific, reagent-aware dewatering guidelines or framework, recognising that any pH, ionic strength and dosage optima identified are system-specific rather than universal, so that any resulting guidelines or procedures on coagulant/flocculant selection and dosing should be validated against the specific ore mineralogy and reagent suite in use, rather than transferred directly from the water-treatment literature or any other tailings literature. A minimum evidence base of three to four contrasting ore types (e.g. a sulfide, a PGM-bearing and an oxide/silicate system) tested under a common C-F-S protocol would be required before guidelines could reasonably be generalised beyond the siliceous Merensky reef systems studied to date (Manono et al., 2024a, 2024b; Shamukuni et al., 2025a, 2025b).

7. Conclusions

This review set out to link flotation reagent chemistry with tailings coagulation-flocculation-sedimentation (C-F-S). It is established, from the literature, that the factors governing C-F-S - pH, ionic strength, dosage, and zeta potential behave consistently, if not identically, across flotation-tailings and general water-treatment systems, and residual dewatering reagents recycled into flotation measurably alter flotation performance and tailings settling behaviour (Manono et al., 2024a, 2024b, 2024c). It can also be inferred that given the functional similarity between several flotation reagents and conventional flocculants, it is mechanistically plausible, but not yet demonstrated, that some residual flotation reagents may produce an analogous effect on C-F-S performance. This review has also shown that there remains unexamined behaviour, in the sense that direct, quantitative evidence for the specific effect of flotation reagent carryover on thickener performance remains confined to a single research group and ore type; and the typical residual concentrations of flotation reagents in thickener feed, relative to deliberate coagulant and flocculant dosing, have not been reported. Closing this gap would clarify whether flotation reagent selection should be treated as a variable relevant to dewatering performance and reclaimed water quality, and would support the more integrated, water-efficient circuit design that closed-water and dry-stacking operations require.

Author Contributions

M.S.M. and K.C.C.: conceptualisation, methodology; M.S.M.: data curation, writing—original draft preparation; M.S.M. and K.C.C.: visualization, investigation; K.C.C.: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

Use of AI and AI-assisted Technologies

No AI tools were utilised for this paper.

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