Modernizing Soluble Salt(s) Flotation Circuits

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Extended Abstract

Abstract

Soluble salt flotation faces unique challenges: operation in saturated brine creates high viscosity and complex ion chemistry; limited reagent options are further constrained by brine conditions; and particle sizes often exceed 1mm—dramatically larger than in metallic ore processing. These factors necessitate an integrated approach to circuit design. Modern solutions combine advanced modeling with current solubility data, real-time mineralogical monitoring, precise crushing for particle size distribution control, and innovative technologies specifically targeting coarse fraction flotation. This paper outlines the comprehensive methodology required to design efficient, contemporary salt flotation circuits that simultaneously address the multifaceted challenges of processing salt, potash, and sulfates in saturated environments.

Soluble Salt Mineralogy

Economically valuable soluble salt deposits are found in many underground marine evaporite formations and brines from land-locked water bodies like the Dead Sea, Salar de Atacama, and certain dry lakes in Western Australia. The predominant minerals found in these deposits are sylvite (KCl) and halite ($NaCl$), usually found as a mixture called sylvinite (Donald E. Garrett, 1996). In many deposits, carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$) may also be found. Sulfates such as kieserite ($MgSO_4 \cdot H_2O$) mixed with sylvite as "hartsalz" occur in zones like the Zechstein Basin. Double salts like kainite ($KCl \cdot MgSO_4 \cdot 2.75H_2O$) have been found in Sicily and are present in Ethiopia. In areas around Carlsbad, New Mexico, langbeinite ($K_2SO_4 \cdot 2MgSO_4$) occurs extensively. In the Amazon Basin, tachyhydrite ($CaCl_2 \cdot 2MgCl_2 \cdot 12H_2O$), associated with sylvinite, may also be found. These variations add complexity to the beneficiation of soluble salts.

Impurities associated with soluble salts include sparingly soluble salts. These could be anhydrite ($CaSO_4$), Ca and Mg carbonates, as well as various other clay minerals, all of which have a detrimental impact on flotation.

The salts present in the flotation feed have a major impact on flotation circuit performance. For complex ores, advanced online measurement technologies such as laser LIBS systems, similar to the one used in Mars explorations, are becoming a viable option for replacing K^{+40} analyzers and other older technologies.

Flotation Brines

Soluble salt flotation must be carried out in saturated brine—a highly concentrated electrolyte system. The properties of an aqueous system at such a high electrolyte concentration are very different from dilute aqueous solutions employed in conventional flotation systems.

The high ionic strength of the media results in a compressed electrical double layer and reduces the range of the electrical forces operating between particles, which impacts flotation performance.

Saturated brines tend to be in equilibrium with the solid phase; therefore, their concentration fluctuates when there are changes in the solids' chemical composition, as well as changes in ambient temperature, making it a highly dynamic system. Figure 1 shows the Na-K-Cl-H_2O solubility chart, probably the simplest of all systems encountered in soluble salt flotation. It demonstrates how the solubility of the two salts changes with temperature. It is therefore important to minimize temperature changes (day/night and summer/winter) at all possible costs.

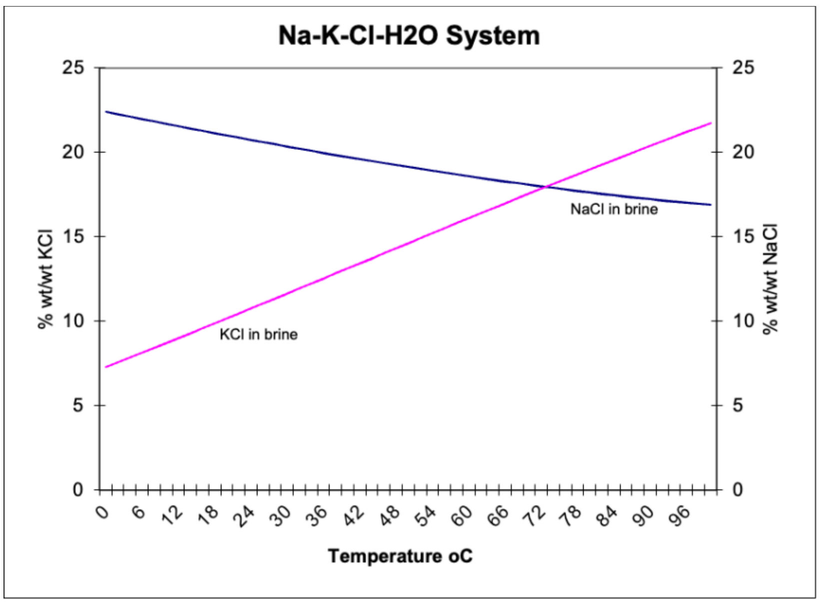

Figure 1: The Na-K-Cl-H_2O solubility chart

The sudden presence in the flotation of another soluble salt like carnallite will progressively increase the concentration of magnesium [Mg^{2+}] in the brine. This will produce the sudden precipitation of fine NaCl and KCl particles from the bulk solution, thus changing the conditions under which flotation is taking place. Fine precipitates will capture available collector and will also influence froth stability to the detriment of flotation performance.

In more complex systems, such as those encountered in potassium sulfate flotation, changes in brine chemistry are more difficult to predict and manage (Figure 2).

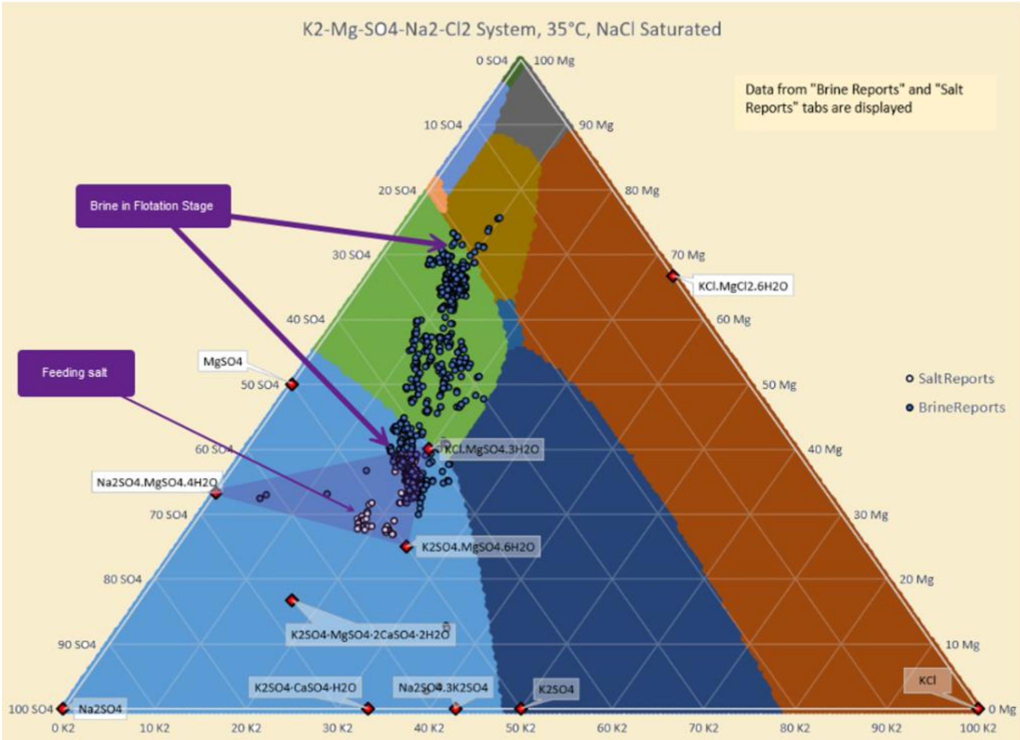

Figure 2: Complex chlorides and sulfates system

Therefore, to be able to predict and adapt to changes in the feed salts, suitable modeling tools are required for predicting solubility changes in these multicomponent aqueous systems with high ionic strength.

Available Reagents

Suitable flotation reagents for soluble salt flotation are very limited in their variety and in their production sources.

Potassium chloride (sylvite) is usually floated from sodium chloride using primary aliphatic amines. Temperature fluctuations between summer and winter affect sylvite flotation performance. Flotation performance deteriorates when brine temperature rises. Due to the fact that the effective flotation of KCl depends upon the formation of insoluble collector species, increased temperature, which promotes amine solubility, depresses flotation (Gefvert, 1987). To counteract the effect of temperature, most flotation circuits employ longer chain amines in the summertime as they are less soluble.

Sodium chloride (halite) is floated using a cationic collector of the alkylmorpholine family, which have high selectivity but also are of relatively high cost. Alkylmorpholines are also not soluble in water but are sufficiently dispersible to be added undiluted to conditioners. Flotation pH needs to be adjusted to around 5 for maximum selectivity. Alkylmorpholines are less influenced by brine temperatures than aliphatic amines but equally sensitive to impurities such as clays and finely dispersed salts.

Particle Sizes that Push the Limits of Flotation Machines

One key parameter that differentiates soluble salt flotation from most other flotation systems is the size of the particles to be floated. Most soluble salts mined from underground mines or harvested from solar evaporation ponds liberate at fairly large particle sizes. Most sylvinites mined in Canada or in Russia, the two largest producers, liberate at around 1 mm or slightly larger. Solar pond salts don't have a liberation size per se, but crystal sizes reach up to 800-900 microns.

Potassium chloride (sylvite) flotation circuits normally float particles up to 1 mm in size, and in some cases even coarser—up to 2.5 mm. Sodium chloride flotation circuits also deal with rather coarse size distributions, but in this case the available collector sets the limit of how coarse particles can be floated, normally at around 600 microns.

Saturated brines usually develop conditions such as high densities and viscosities, which further hinder flotation performance. Most soluble flotation brines have densities in the range of 1.23 to 1.40. Viscosities, especially in those high Mg^{2+} brines, can reach values in the region of 3.2 cP. Flotation of the finer size fractions under these conditions becomes extremely difficult. Flotation of particles in the range of 150 microns and smaller is possible, but at much lower selectivities.

Therefore, comminution and flotation need to be integrated into a single optimization exercise. Target crushing sizes need to maximize the coarser fractions of the particle size distribution up to the very limit of what the flotation equipment and available reagent can handle, while at the same time minimizing the amount of fine sizes below the 150-micron threshold. This will assist in maximizing flotation recoveries. Comminution circuits feeding flotation in soluble salt systems usually consist of up to three, sometimes four stages of impact-type crushers separated by highly efficient classification stages. This ensures an optimum size distribution while minimizing fine generation.

Flotation equipment needs to be selected to maximize recoveries along the extended particle size distribution. Conventional mechanical flotation cells are proven to deliver good selectivities and recoveries in the size ranges between 250 microns and up to 1 mm when floating sylvite. When floating halite, the top size floatable in a conventional flotation cell is only 600 microns. This is due to limitations in the available collector rather than limitations on the flotation equipment. Pneumatic and contact flotation cells, both of which can achieve high selectivities and recoveries, are effective in floating the finer size fraction down to 100 microns. In some sylvinite flotation circuits, Hydrofloat flotation machines are used to float particles above 1 mm in size. Because halite is the heavier of the mineral species, in halite flotation circuits, such as those floating halite from sulfates or from carnallite, Hydrofloat-type cells are not applicable. Flotation of coarse halite particles is therefore ripe for new developments.

Optimizing flotation of such coarser size distributions requires separate conditioning to ensure optimum reagent coverage and maximum hydrophobicity of the larger sizes. For best reagent usage, in some cases 80% of the collector is added to condition the 20% coarser size fractions, whilst the finer fractions, below 200 microns, don't need any collector added as they are made hydrophobic by adsorbing residual reagents dispersed in the brine.

Effect of Insoluble Clays and Other Very Fine Particles

Sylvinite ores mined from underground deposits usually contain from 2-20% insoluble material, occurring as finely dispersed silicates, carbonates, and in some cases, anhydrite. Soluble salts from evaporation ponds also contain insoluble impurities that come as wind-blown dust into the ponds and sometimes material from the pond floor that is grabbed by the harvesting machines when not properly operated.

Due to the insoluble slimes' high adsorptive capacity for most commonly used collectors, these must be sufficiently removed to permit an efficient soluble salt flotation.

Insoluble slimes also attach themselves to the coarser salt particles, causing a loss in separation efficiency, as their surfaces are coated with slimes and become inaccessible to flotation reagents. Froth stabilization is another consequence of insoluble fines in the flotation feed, as they tend to get trapped in the froth, making it stable and less competent to float coarse salt crystals.

The deleterious effect of the insoluble slimes can be minimized by implementing a desliming step ahead of the main flotation circuit. Depending on the insoluble main mineralogy, desliming can be done via mechanical separation, using cyclones and hydroclassifiers. When some naturally floating clays are present in the feed, desliming via flotation can become the only available option. Desliming can have the effect of reducing recoveries, and some of the finer valuable salts could also be lost with the insoluble salts. An efficient desliming circuit might entail several stages of cycloning or of flotation to be able to operate at minimum recovery losses.

Conclusion

The approach for modern and efficient soluble salt flotation circuit design includes several steps that need to be taken into consideration: first, it is imperative to have good working knowledge of the mineralogy of the feed salts, with detailed geometallurgical studies to properly identify the main minerals, the impurities, and their associations. An online analyzer is recommended for close monitoring of any variation in the feed salts. Second, modeling and simulations using up-to-date solubility data are critical to maintain control on the flotation brine chemistry. Third, a surgical comminution circuit capable of feeding flotation with a particle size distribution that allows for the maximization of floatable material while minimizing the unwanted fines. Fourth, it is necessary to have a proper mix of flotation technologies that allow for maximum recoveries all along the feed size distribution. In some soluble salt flotation circuits, such as those floating sylvinite, the product of the flotation circuit is the final saleable product. It is, therefore, imperative that the design of the circuits is efficient and up-to-date in order to achieve optimum results.

Bibliography

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