



## Copper ores

The main copper sulphide minerals are chalcopyrite ( $\text{CuFeS}_2$ ), chalcocite ( $\text{Cu}_2\text{S}$ ), covellite ( $\text{CuS}$ ), bornite ( $\text{Cu}_5\text{FeS}_4$ ), tetrahedrite ( $(\text{Cu,Fe})_{12}\text{Sb}_4\text{S}_{13}$ ) and enargite ( $\text{Cu}_3\text{AsS}_4$ ). The largest source of copper is from porphyry ore deposits in which one or a combination of the aforementioned minerals occurs. A typical copper sulphide ore contains various levels of iron sulphide types that generally include pyrite ( $\text{FeS}_2$ ) and pyrrhotite ( $\text{Fe}_{1-x}\text{S}$ ). Often gold and silver are present which may either be associated with the sulphides or are free. The gangue particles can consist of a range of silicate minerals from quartz to talc and clays. Carbonate mineral gangue can also be present.

When liberated, typical copper sulphide minerals are relatively easy to float. When there are no overriding metallurgical issues, producing a sufficiently high copper concentrate grade is often the focus. Often the primary grade control issue relates to iron sulphide minerals since these also float with the copper, diluting copper concentrate grades. This is related as: 1) iron sulphide mineral levels are usually much higher than copper concentration, 2) sulphide flotation collectors can float iron sulphides well also, 3) liberation can be an issue making copper and iron separation difficult, and 4) fine particles are often more difficult to separate. A frequent and vexing challenge is that precious metals (gold and silver) are often present in iron sulphides and rejection of these minerals impacts economics.

Gangue slimes (typically clays and talc) can be an issue because of preferential adherence to bubble surfaces that 'crowd out' copper mineral collection onto bubbles. Misplacement of gangue slimes to concentrates also can pose significant concentrate dilution issues as well as requiring much higher flotation residence times to ensure high copper mineral recovery. In a plant where the flotation capacity is fixed, this means lower copper recoveries. Dispersants such as sodium silicate, polyacrylates, and sodium hexametaphosphate are often used to minimize fine gangue slimes bubble adhesion and minimize impact on copper recovery. Alternatively, CMC (carboxymethyl cellulose), dextrin, or starches can be effective gangue depressants.

Iron sulphide mineral depression is normally controlled with lime addition at pH levels as high as 11+. While some operations float at a natural pH, at least in roughing, in these cases the combination of reagent selection and relative pyrite floatability is controllable. Even when neutral pH is used in roughing, the cleaner flotation stages are generally conducted at higher pH to ensure iron sulphide depression. When gold is present and of significant value, unfortunately lime can also reduce gold recoveries particularly if free or are associated with iron sulphide minerals.

Cyanide can also be an effective iron sulphide depressant, where use is allowed, but cyanide can solubilize metal ions which may activate a wide range of mineral sulphide minerals which can negatively impact flotation selectivity. In some instances, soda ash or caustic soda may be used to control flotation selectivity. Another option that has been beneficial is utilizing pulp preaeration which can cause oxidation on more reactive mineral sulphide surfaces making them less floatable; of course the effectiveness of this technique is dependent on the mineralization and circuit characteristics.

Standard copper sulphide flotation collector reagents are sulfur based thiol class collectors which can be grouped into the main xanthate, dithiophosphate, thionocarbamate and thiocarbamate families. Other chemistries are also effective and fill separate classes but as a

general common characteristic these generally have double bonded sulfur atoms in their structure through which chemical bonding to the copper mineral surfaces is effected. Effective flotation collector reagent selection is dependent on the sulphide minerals present, their mineral associations in the ore, and circuit characteristics. Because an ore typically has more than one copper sulphide mineral type, often a combination of sulphide flotation collectors is used to maximize metallurgical performance. These are added separately or, as is becoming common, are supplied as blended products to optimize flotation.

Frothers are an important flotation reagent suite consideration. Frother chemistries are wide ranging and generally include alcohols of varying structures and molecular weights, aldehydes/esters, and glycols with these used alone and as blends. These modify the bubble surface tension which impacts bubble size formation, bubble surface hydrodynamics, and mineral carrying capacity on the cell surface all of which impact copper sulphide flotation and optimization. Often the collector-frother combination must be considered and evaluated to optimize flotation circuit performance.

Oxidized ("tarnished") minerals pose flotation recovery issues, which often is significant. Where oxidized minerals are a discernable issue, treatment options include flotation collector changes and sulphidization with either metabisulphide or  $\text{SO}_2$ . Sulphide flotation of actual oxide copper minerals (such as malachite, azurite) is not possible with sulfhydryl mineral flotation collectors and either other oxide type collectors are required or alternative mineral beneficiation routes must be considered.

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### The following Danafloat™ collectors alone and in combinations should be initially considered for copper flotation:

Danafloat™ 067  
 Danafloat™ 068  
 Danafloat™ 070  
 Danafloat™ 233  
 Danafloat™ 245  
 Danafloat™ 262E  
 Danafloat™ 345  
 Danafloat™ 507E  
 Danafloat™ 871

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### Consider for ores that contain oxidized copper minerals:

Danafloat™ 271  
 Danafloat™ 571