

Flotation Guidebook

Orica Mining Chemicals

The Power
of Partnership



PLEASE NOTE

The flotation reagents listed in this book are current as of June 2009. The user should make contact with their local Orica Mining Chemicals representative prior to testing and purchase, to ensure that the relevant products are available at the time of intended use.

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FURTHER INFORMATION

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Orica Mining Chemicals
Flotation Guidebook

Orica Emergency Response Number
1800 033 111 (All Hours)

Flotation Guidebook

Orica Mining Chemicals



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Safe Handling of Orica Flotation Reagents

Flotation Guidebook



'No injuries to anyone, ever'

Orica seeks to be among the best performers internationally in safety, health and environment (SH&E) consistent with the Company aim to 'Deliver the Promise' in all aspects of its activities.

The Company values include a commitment to operate to the highest standards of safety, health and environment, recognising that nothing is so urgent or important that the time cannot be taken to do it safely. One of the four key principles for the Company is 'SH&E – Ensuring our Future' and the SH&E Vision of 'No Injuries to Anyone, Ever', 'Value People and the Environment' symbolises Orica's commitment to eliminate all work related injuries, illnesses, motor vehicle incidents, environmental incidents, complaints and other adverse SH&E incidents and acknowledges the belief that all such incidents are preventable.

In addition Orica's SH&E Vision gives a commitment to manage its activities to meet the needs of our customers and the community in an environmentally sustainable manner, for the benefit of society and without compromising the quality of life of future generations. Orica's aim is to continually reduce the number of injuries and other adverse SH&E incidents.

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The table below summarises the classification of substances that flotation chemicals are divided into. For more specific information about individual Orica products please refer to the corresponding product MSDS.

Class	Flash Point	Dangerous Good	Definition
Flammable Liquid Class 3	< 60.5°C	Yes	A liquid having a flash point below 60.5°C.
Combustible Liquid – C1	60.5 to <150°C	DG only for storage purposes	A liquid having a flash point greater than 60.5°C but less than 150°C.
Combustible Liquid – C2	>150°C	DG only for storage purposes	A liquid having a flash point greater than 150°C.
Spontaneously Combustible Solid Class 4.2	NA	Yes	A self-heating material that can ignite without an external ignition source. It will usually only ignite when present in large volumes (at least kilograms) and after a long period of exposure (at least hours and usually days).
Corrosive Substance Class 8	NA	Yes	A liquid or solid that is capable of causing the degradation and destruction of living tissue, steel and other materials on contact.

Data based on the Australian Dangerous Goods Code, 7th Edition.

1.1 Collectors

Dithiophosphates (DTP's)

All the DTP's are classified as dangerous goods, Class 8 corrosive liquids.

Thionocarbamates (TNC's)

Pure TNC's are mostly non-dangerous goods (non DG), for example Orica specialty collectors DSP 009 and DSP 115. Some other products in the TNC range may be classified as Class 3 dangerous goods dependent on the residual alcohol content.

Xanthates

All of the xanthate products (PAX, SIBX, SIPX, SEX) are classified as dangerous goods, Class 4.2 spontaneously combustible.

1.2 Frothers

Most of the frothers in the Orica product range, with the exception of MIBC, are classified as non-dangerous goods. MIBC is a Class 3 flammable liquid.

1.3 Suggested PPE

- Wear clothing that offers ankle to wrist coverage
- Wear impervious gloves
- Wear chemical goggles if a risk of splashing/spray exists
- Wear respirator (as per AS/NZS 1715 and AS/NZS 1716) if risk of inhalation exists



1.4 Safe Practice

- Use reagents in areas with adequate ventilation
- Do not breathe dust/vapour/mist/aerosol.
- Avoid contact with skin and eyes.
- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
- Wear suitable protective clothing, gloves and eye/face protection

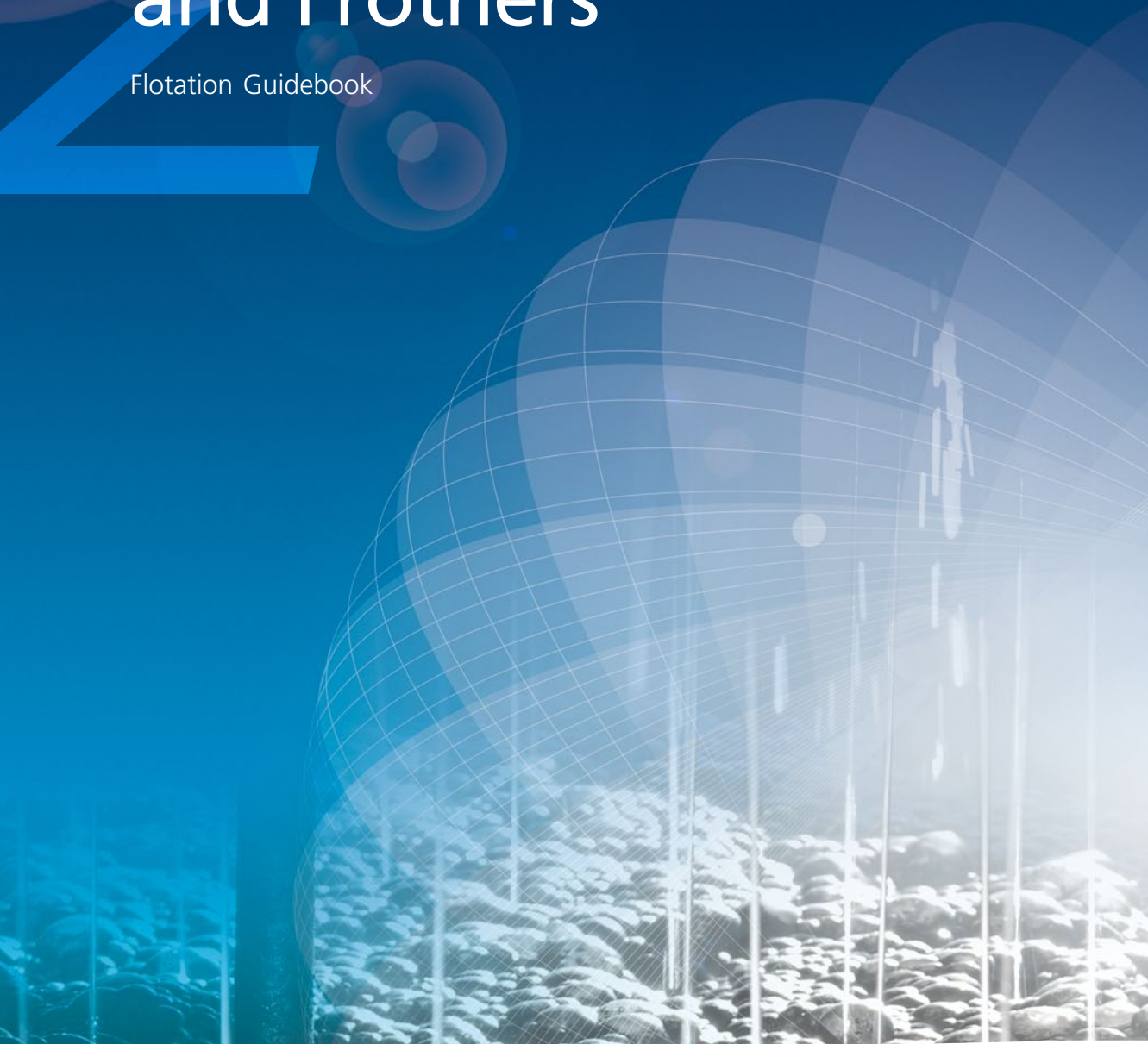
Contact your nearest Orica Mining Chemicals representative for more information about the physical properties of each reagent, up to date MSDS and any safe handling enquiries.

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First Choice Guide – Specialty Collectors and Frothers

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The table below is a quick reference guide to enable the metallurgist to choose a specialty collector and frother that should have the best initial chance of successfully floating a particular ore. Further optimisation can then be performed using other reagents detailed in this guide if needed. Orica’s collectors and frothers can also be specially formulated to meet individual site requirements and ore types.

Ore Type	Specialty Collector	Specialty Frother		
		Weak	Medium	Strong
Gold	DSP 413, DSP 007 or DSP 634	DSF 004A	DSF 001A	DSF 002A
Copper	DSP 009, DSP 115 or DSP314	DSF 004A or MIBC	DSF 001A or DSF 802	DSF 611
Zinc	DSP 009 or DSP 115	DSF 004A or MIBC	DSF 510	DSF 002A
Lead	DSP 330A	DSF 004A or MIBC	DSF 510	DSF 002A
Nickel	DSP 115, DSP 413 or DSP 432	DSF 004A	DSF 507	DSF 620
Copper, Gold	DSP 110 DSP 314 or DSP 634	DSF 004A	DSF 802 or DSF 109A	DSF 620
Copper, Zinc	DSP 009 or DSP 115	DSF 004A or MIBC	DSF 510	DSF 611
Lead, Zinc	DSP 330A (Pb) and DSP 009 (Zn)	DSF 004A or MIBC	DSF 510	DSF 611
Copper, Lead, Zinc	DSP 009 (Cu), DSP 330A (Pb) and DSP 009 (Zn)	DSF 004A or MIBC	DSF 510 or DSF 109A	DSF 611

Note: In multi-element systems, depression and re-activation with additional reagents is usually required. Refer to Section 6 for detailed processing options.

Specialty Collectors

Flotation Guidebook



3.1 Dithiophosphates

Name	Reagent	Strength	Suitability								
			Cu	Pb	Zn	Fe	Au	Ag	Pt, Pd	Ni	
DSP 012	Sodium diethyl dithiophosphate	Weakest and most selective dithiophosphate collector	•		•				•		•
DSP 011	Sodium di-isopropyl dithiophosphate	Stronger than DSP 012	•		•				•	•	•
DSP 007	Sodium di-isobutyl dithiophosphate	Stronger than DSP 011	•		•			•	•	•	•
DSP 002	Sodium dibutyl dithiophosphate	Similar to DSP 007	•		•			•			•

Note: All Orica specialty collectors are used undiluted.

DSP 012

The weakest and most selective dithiophosphate. It is good for copper, zinc, silver and nickel flotation, especially where activated minerals are present and selectivity is an issue.

DSP 011

A selective collector, suited for recovery of copper, gold, silver and zinc sulphides. Used where greater recovery is needed than that obtained with DSP 012.

DSP 007

A good collector for gold and base metals. Has been used successfully for the flotation of gold bearing sulphide ores especially synergistically with xanthates where it provides extra gold and sulphur recovery at high grades.

DSP 002

A strong dithiophosphate collector. It has been shown to improve gold recovery. It can be used by itself or as a booster in combination with xanthates, especially in scavenging applications. Good for copper sulphide and nickel flotation.

3.2 Thionocarbamates

Name	Reagent	Strength	Suitability							
			Cu	Pb	Zn	Fe	Au	Ag	Pt, Pd	Ni
DSP 009	Isopropyl ethyl thionocarbamate	Stronger than dithiophosphate	•		•					
DSP 032	Allyl isobutyl thionocarbamate	Similar to DSP 009	•		•		•	•	•	
DSP 010	Isobutyl ethyl thionocarbamate	Similar to DSP 009	•		•					

DSP 009

A very popular and effective thionocarbamate collector for all forms of copper mineralisation and zinc. DSP 009 shows fast flotation kinetics and improved selectivity over iron sulphides such as pyrite and arsenopyrite in alkaline circuits especially for copper and copper-gold ores. Is usually used alone without the aid of other collectors and has the potential to replace xanthate when used in copper and zinc flotation. Can also be used on the high grade nickel ore when significant amounts of iron sulphides are present.

DSP 032

Excellent for copper recovery over a wide pH range. Excellent selectivity for Cu-Zn as well as the recovery of associated Au, Ag, Pt, Pd, and Mo. When used in conjunction with xanthates, selectivity is improved and the xanthate dosage can be reduced.

DSP 010

Good copper and zinc collector. Has been used effectively to supplement xanthate performance, especially in copper-gold and copper-zinc operations.



3.3 Formulated Collectors

Name	Reagent	Strength	Suitability								
			Cu	Pb	Zn	Fe	Au	Ag	Pt, Pd	Ni	
DSP 017	Proprietary dithiophosphate / thionocarbamate blend	Similar strength to DSP 009 but more selective	•		•			•			•
DSP 020	Proprietary dithiophosphate / thionocarbamate blend	Similar to DSP 017	•					•			•
DSP 052	Proprietary dithiophosphate / thionocarbamate blend	Similar to DSP 017	•		•			•			•
DSP 100	Proprietary thionocarbamate blend	Stronger than DSP 020	•		•			•	•	•	
DSP 110	Proprietary thionocarbamate blend	Similar strength to DSP 100	•		•			•	•	•	
DSP 115	Proprietary thionocarbamate blend	Similar strength to DSP 009	•		•			•			•
DSP 120	Proprietary thionocarbamate blend	Similar to DSP 110	•		•			•			•
DSP 013	Proprietary dithiophosphate blend	Similar to DSP 007 and DSP 002	•		•			•	•	•	
DSP 315	Proprietary dithiophosphate blend	Similar to DSP 007 and DSP 002	•		•			•	•	•	
DSP 634	Proprietary dithiophosphate / monothiophosphate blend	Similar to DSP 007 and DSP 002	•		•			•	•	•	
DSP 330A	Proprietary mercaptobenzothiazole blend	Stronger than dithiophosphates		•			•	•	•	•	•
DSP 314	Proprietary dithiophosphate / mercaptobenzothiazole blend	Similar strength to DSP 330A	•				•	•	•	•	•
DSP 432	Proprietary thionocarbamate / mercaptobenzothiazole blend	Stronger than DSP 314	•				•	•	•	•	•
DSP 413	Proprietary dithiophosphate / mercaptobenzothiazole blend	Stronger than dithiophosphates					•	•	•	•	•

DSP 017, DSP 020 and DSP 052

These collectors are suited to the recovery of copper, gold, silver and zinc sulphides. Excellent for gold recovery from Cu/Au systems. Can be used as a secondary booster with xanthate or by itself. They are also good for coarse particle flotation and scavenging applications for nickel ores.

DSP 100, DSP 110, DSP 120, DSP 115

All of these reagents are effective copper and copper-gold collectors. Suitable over a wide range of pH. They have been shown to improve gold recovery without affecting copper grade time and time again. Similar to DSP 009 and DSP 010, applicable to a wide range of base metal ores including copper, zinc and nickel with fast kinetics. When tested on nickel ores, DSP 115 gives efficient separation of nickel and iron from MgO gangue and has the potential to enable xanthate and frother levels to be reduced. DSP 115 can also be used at low pH.

DSP 013, DSP 315 and DSP 634

Similar in strength and performance to DSP 007. These reagents provide additional recovery at a high grade for copper-zinc systems and precious metal ores. DSP 634 has very good selectivity for free gold and has been used effectively on low grade copper-gold ores. In a laboratory programme, it is a good idea to consider testing all of these reagents to see which one works the best.

DSP 330A

An effective pyrite and gold collector in natural pH circuits. It can also be used to float lead from zinc and has shown good tendency to recover tarnished sulphide minerals.

DSP 314, DSP 432 and DSP 413

Excellent for gold and copper recovery, especially when used on low grade ores with variable mineralogy. DSP 432 and DSP 413 have been used successfully on lower grade nickel ores that contain lesser amounts of iron sulphides. When used in nickel flotation they have been found to provide extra recovery and grade compared with xanthates and enhanced selectivity towards iron and against MgO. They have been shown in the past to be a one for one replacement for xanthate in nickel flotation.

3.4 Xanthate Replacement Quick Reference Table

This table lists the Orica Mining Chemicals specialty flotation collectors that are most suitable as 1 for 1 replacements for xanthate, depending on the ore type and the most predominant minerals present. The reagents detailed below offer similar performance at an equivalent or lower dosage. All the Orica specialty collectors are added neat (ie. they are not diluted with water).

Ore Type	Typical Minerals	Xanthate	Orica Specialty Collectors	Dosage
Nickel	Pentlandite, Millerite	SEX, SIBX	DSP 413, DSP 432, DSP 115	Equivalent or less
Copper/Gold	Chalcopyrite, Chalcocite, Bornite, Pyrite, Arsenopyrite	PAX, SIBX	DSP 110, DSP 634, DSP 314	Equivalent or less
Copper	Chalcopyrite, Chalcocite, Bornite	SIBX, SIPX, SEX	DSP 009, DSP 115, DSP 032, DSP 012, DSP 634	Equivalent or less
Zinc	Sphalerite	SIBX, SIPX, SEX	DSP 009, DSP 115, DSP 032, DSP 017	Equivalent or less
Lead	Galena	SEX, SIPX	DSP 330A	Equivalent or less

Note: Dosage of specialty collectors should be confirmed with laboratory testing and plant trialling.

3.5 Plant Operation Tips

- The sequence of addition of modifiers, collectors and frothers is of great importance, especially when sulphidising agents and other activators and depressants are involved. This is because flotation is a process that relies heavily on surface chemistry, and the order that these reagents are used can mean the difference between successfully making a mineral surface hydrophobic and floating it, or leaving it behind with the gangue. With this in mind, careful consideration should be taken when selecting reagent dosing points in the plant so that recovery and grade are optimised.
- Some of Orica's collectors DSP 009, DSP 032 and DSP 010 are non water-soluble. For best results in the plant, it may be beneficial to add these collectors to the mill to improve conditioning, i.e. dispersion and contact time with the mineral. This should also be trialled when high losses are occurring due to the creation of fine particles (over sliming). The idea being that as small particles are generated in the mill, they are immediately coated with collector and more ready to float straight away.
- When trialling additional or different collectors maintain a visual inspection history of the froth and concentrate in each circuit via online monitoring or digital photos.
- Collect mass and assay data from each shift over the duration of the trial so that shift recoveries and grades can be determined and to ascertain whether the trial collector is better or worse than the incumbent collector. To this end, if possible, the trial should be designed in a way that comparative statistics can be used to analyse the results and ascertain whether a benefit is likely to be achieved for the trial condition (refer to section 7).

Commodity Collectors and Modifiers

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4.1 Xanthates

Xanthates		Relative Strength	Typical Plant Solution Strength %
Sodium Ethyl Xanthate	SEX	Weak	10 – 20
Sodium Isopropyl Xanthate	SIPX	↓	10 – 20
Sodium Isobutyl Xanthate	SIBX		10 – 20
Potassium Amyl Xanthate	PAX	Strong	15 – 25

Xanthate collectors are salts consisting of a non-polar hydrocarbon group, which provides the hydrophobicity to a sulphide mineral, pointing outward from the mineral to the solution, and a polar group that adsorbs onto the sulphide mineral surface. The longer the hydrocarbon chain on the xanthate molecule, the stronger the hydrophobicity is likely to be. Hence, sodium ethyl xanthate (SEX) with two carbon molecules in the chain, is the weakest xanthate and is used where selectivity is most important. It is applicable to the flotation of minerals that are already activated or partially hydrophobic and float easily, such as activated zinc, nickel and lead. At the other end of the scale, potassium amyl xanthate (PAX), with 5 carbon molecules in its chain, is strong, unselective, and is ideal for sulphide gold operations where all sulphide minerals need to be recovered. Sodium isopropyl xanthate (SIPX) and sodium isobutyl xanthate (SIBX) are typically used when the collector needs to be stronger than SEX without compromising too much on selectivity, for instance in some copper-gold, copper-zinc and nickel operations. In some parts of the world where potassium hydroxide is more readily available than sodium hydroxide for xanthate manufacture, the use of xanthates such as PEX (potassium ethyl xanthate) and PIBX (potassium isobutyl xanthate) may be more common.

4.2 Decomposition of Xanthate Solutions

(See also Section 9)

Xanthates, whether in solid or liquid form are known to decompose over time to species including carbon disulphide (CS₂), an alcohol (R-OH), carbonate (CO₃²⁻) and trithiocarbonate (CO₃²⁻) (NICNAS, 1995). The decomposition rate for sodium ethyl xanthate (SEX) is given in figure 1 (American Cyanamid Company, 1972) where the measurements were conducted on 10% SEX solutions at pH 10. As pH decreases below pH 7, xanthate decomposes more rapidly and below pH 6.5 the decomposition is approximately 16% per day. The rate of decay can be reduced by increasing the pH of the solution. Even though only data for SEX is presented here, the decomposition rates for SIPX, SIBX and PAX are known to be very similar. They decompose less rapidly the longer the chain length, ie. PAX will decompose less rapidly than SIBX and this in turn decomposes less rapidly than SIPX. Also, it should be noted that the greater the xanthate solution strength, the faster it will decay. For example 20% xanthate solutions decompose more rapidly than 10% solutions.

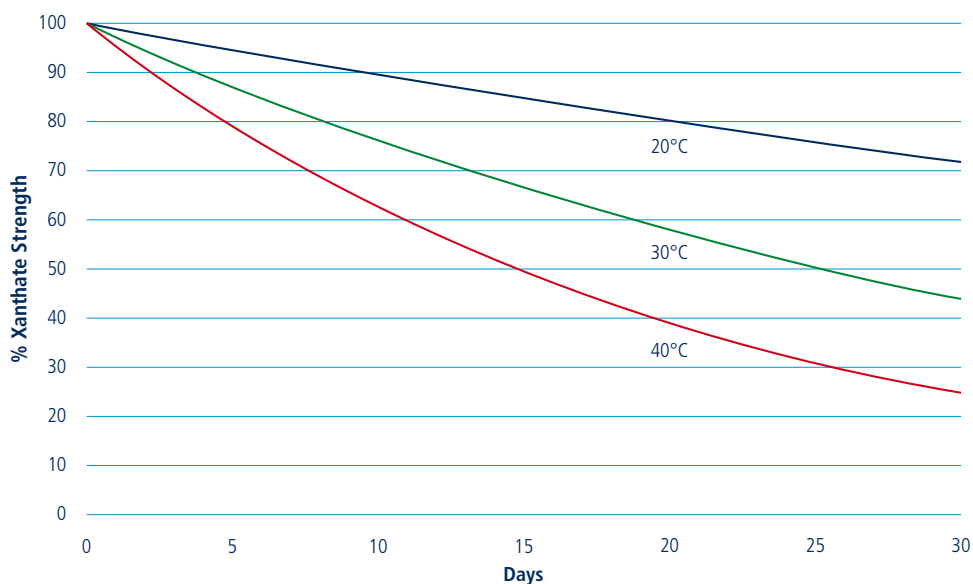


Figure 1. Decomposition rate of Sodium Ethyl Xanthate solution.

4.3 Modifiers

Modifiers are reagents that either increase or decrease the ability of a collector to provide the hydrophobicity required to float various minerals. The application of a modifier is strongly dependent on the ore mineralogy, including the quantity and variability of gangue minerals. In some instances gangue minerals can be recovered initially, using just a frother with depressants in a pre-float, for example to remove talc or carbon. A selection of widely used activators, pH modifiers and depressants is presented below.

Activators		Application
Copper Sulphate	CuSO_4	Activation of sphalerite, pyrite, arsenopyrite, pyrrhotite, pentlandite. Also used to reactivate the same minerals if they have been depressed with cyanide. Usually made up to 15-25 % solution strength.
Lead Nitrate	$\text{Pb}(\text{NO}_3)_2$	Activation of antimony sulphide minerals and to reactivate copper sulphides depressed with cyanide.
Sodium Sulphide / Sodium Hydrosulphide <i>See also depressants</i>	Na_2S / NaHS	At medium dose rates, can be used as an activator for oxidised and tarnished minerals. The choice of whether to use Na_2S or NaHS depends on the pH required in flotation, as Na_2S is more alkaline and also, whichever works best (test to verify). Typically made up to 15-25 % solution strength.
Sodium Cyanide <i>See also depressants</i>	NaCN	Can be used to activate lead-sulphide mineral surfaces.

pH Modifiers		Application
Lime	CaO	Used to raise pH and depress pyrite during copper and zinc flotation. The pH modifier that is selected will be dependent on cost, availability, effect on viscosity and potential build up of scale in the plant. Note if Au or Ag are associated with pyrite and Fe sulphides, then their recoveries may also be adversely impacted.
Sodium Hydroxide	NaOH	Also known as Caustic Soda. Used to raise pH.
Sodium Carbonate	Na ₂ CO ₃	Also known as Soda Ash. Used to raise pH and as a dispersant when lime is causing scale and/or viscosity problems.
Sulphuric Acid	H ₂ SO ₄	Used when flotation needs to be at a lower pH.

Depressants		Application
Sodium Cyanide	NaCN	Strong sulphide depressant for iron and zinc sulphides (eg. pyrite, pyrrhotite, marcasite, arsenopyrite, sphalerite).
Sodium Metabisulphite	SMBS	Depression of Zn sulphide (sphalerite) and Fe sulphide (eg. pyrite, pyrrhotite) minerals.
Sodium Sulphide / Sodium Hydrosulphide	Na ₂ S / NaHS	At low dose rates (below 500 g/t), can be used as to depress Zn sulphide (eg. sphalerite) and Fe sulphide (eg. pyrite, pyrrhotite) minerals. At high dose rates (above 500g/t), it can be used to depress all sulphides (reverse flotation), allowing gangue to float and be removed.
Lime*	CaO	Depressant for pyrite during copper and zinc flotation and in other sulphide ores where pyrite is a problem.
Carboxymethyl cellulose	CMC	Depression of silicate gangue (eg. talc, serpentine, lizardite, antigorite).
Guar Gum		Depression of silicate gangue (eg. talc, serpentine, lizardite, antigorite).
Zinc Sulphate	ZnSO ₄	Depression of zinc sulphide from lead and copper sulphide minerals. Can be used alone or in conjunction with cyanide.
Dextrin	C ₆ H ₁₀ O ₅	Mostly used to depress carbon minerals during sulphide flotation. Can also be used to depress galena.

* Note: The lime that is added is typically hydrated lime, Ca(OH)₂. This is either supplied as it is or in the form of quicklime, CaO. If it is supplied as the latter, then it is usually 'slaked' on site by the addition of water so that Ca(OH)₂ is again the form that it is added in.

Frothers

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5.1 Weak Frothers

These frothers offer good selectivity, low froth persistence and are usually used at higher dosages.

Name	Reagent	Strength	Properties
MIBC	Methyl Isobutyl Carbinol	Very Weak	A weak frother widely used in most base metal applications.
DSF 800	Proprietary Blend	Very Weak	In some cases weaker than MIBC. Produces a rapidly draining froth, enhancing selectivity.
DSF 004A	Proprietary Blend	Weak	Good general-purpose non-dangerous frother. Provides consistent froth.

Note: All Orica frothers are used undiluted.

MIBC (Methyl Isobutyl Carbinol) – Commodity Frother

A well known, widely used, weak frother which produces a brittle froth. It has found considerable application in base metal flotation. Especially suited to the sulphide ores of lead and zinc at fine particle sizes and high throughputs. It is also used successfully in coal processing.

DSF 800

One of Orica's weakest frothers. Suitable for fine particle flotation. Produces a rapidly draining froth enhancing selectivity. Typical applications include the first rougher cells and as a stage addition in cleaner and re-cleaner cells.

DSF 004A

A weak frother that has been used as the primary frother for large operations. It is ideally suited for fine and medium size particles. Used where high recovery is needed at a good concentrate grade. Has been shown to replace MIBC and has found to be suitable for most base metals and low grade copper-gold ores at high throughput.

5.2 Medium Strength Frothers

These frothers offer a good balance of selectivity, stable froth persistence and can usually be used at lower dosages.

Name	Reagent	Strength	Properties
DSF 001A	Proprietary Blend	Medium	Produces a froth that offers a good compromise between froth stability and selectivity.
DSF 802	Proprietary Blend	Medium-Strong	Produces a robust strong froth for most sulphide ore applications. Performs well in hard water conditions.
DSF 507	Proprietary Blend	Medium-Strong	Produces a froth that offers a good compromise between froth stability and selectivity.
DSF 510	Proprietary Blend	Medium-Strong	Stable, selective frother.
DSF 109A	Proprietary Blend	Medium-Strong	Outstanding frother that produces a stable and selective froth under most conditions.

DSF 001A

This frother is suitable for both coarse and fine particle feed sizes. It offers a combination of good selectivity and froth stability. Typical applications include roughing/scavenging in large capacity flotation cells. It has been used successfully for sulphide gold ores in the range of 1% to 4% sulphur.

DSF 802 and DSF 510

Medium to strong frothers that have found considerable application in large low grade porphyry copper-gold deposits. They produce a robust froth under most conditions and have been found to ignore harsh water conditions including high salinity and high dissolved metallic ions. DSF 611 and DSF 510 have lower viscosity than DSF 802.

DSF 507

A medium strength frother that has been used successfully on nickel ores, especially those that contain MgO and clay based silicate gangue minerals.

DSF 109A

A medium-strong frother that has been found to provide outstanding froth stability and selectivity towards both coarse and fine particles. It has given improved metallurgical performance in terms of grade and recovery at copper-gold and lead-zinc operations.

5.3 Strong Frothers

These frothers are usually used for bulk sulphide flotation. They are less selective, offer excellent froth persistence and generally can be used at lower dosages.

Name	Reagent	Strength	Properties
DSF 002A	Proprietary Blend	Strong	Produces a robust strong froth for most sulphide ore applications.
DSF 611	Proprietary Blend	Strong	Fine to medium sized bubbles, forms a robust stable froth under most conditions.
DSF 615	Proprietary Blend	Very Strong	An alternative to DSF007. Distinguished by fine bubbles, which readily break down in launders.
DSF 007	Proprietary Blend	Very Strong	Produces a persistent stable froth with smaller bubbles from the same volume of air.
DSF 620	Proprietary Blend	Very Strong	Fine to medium sized bubbles with a very strong, robust and stable froth under most conditions.

DSF 002A

Similar to DSF 001A but stronger. Suitable for both coarse and fine particle feed sizes, offering a combination of good selectivity and froth stability. This frother is most applicable to medium to high sulphide gold ores where bulk flotation with a xanthate is carried out.

DSF 611

An excellent strong frother that has been successfully used on large low grade porphyry copper-gold deposits. Produces a robust froth for a wide range of particle sizes.

DSF 007 and DSF 615

Two of Orica's strongest frothers. They produce a persistent froth with smaller bubbles from the same volume of air, thus improving air dispersion in the froth phase. The froth is more stable due to reduced bubble coalescence. Typical applications include coarse particle, flash, and bulk sulphide flotation for high sulphide content ores. Can be used to improve the froth in scavenger cells.

DSF 620

Is a strong frother suitable for use in most sulphide base metal ores, in particular low to high grade nickel ores characteristic of Western Australia.

5.4 Plant Operation Tips

- If initial feasibility testing has been carried out with MIBC, then DSF 800 and DSF 004A may be tested as weak, non-dangerous alternatives. DSF 004A has been used over entire rougher/scavenger and cleaner circuits as a general-purpose frother without any over-frothing issues. Plant operators will notice that the DSF 800 and DSF 004A generate small to medium sized bubbles.
- If one of the weaker frothers has been trialled and is found to have limited strength for the application, try one of the stronger frothers such as DSF 611 or DSF 002A. If these are not strong enough, then try DSF 007.
- If the scavenger cells in a flotation bank are struggling to generate a decent froth (in most cases this can be due to the absence of sulphide minerals), investigate the stage addition of frother at the head of the scavenger cells or try adding a stronger frother. This occurrence is not unusual as most of the sulphides should already have been recovered in the rougher cells and sulphide minerals are needed to form a stable froth.
- When trialling additional or alternative frothers, maintain a visual inspection history of the froth and concentrate in each circuit via online monitoring or digital photos.
- Collect mass and assay data from each shift over the duration of the trial so that shift recoveries and grades can be determined and to ascertain whether the trial frother is better or worse than the incumbent frother. To this end, if possible, the trial should be designed in a way that comparative statistics can be used to analyse the results and ascertain whether a benefit is likely to be achieved for the trial condition (refer to section 7).
- When commissioning or starting up a new operation, especially if a weaker frother such as MIBC has been chosen from the feasibility study, it is a good idea to order a quantity of a stronger frother just in case the weaker frother does not work efficiently on a large scale and gets used up too quickly.
- Fast free-floating gangue can sometimes be floated initially in a pre-float just by adding a frother. This pre-float concentrate can then be disposed easily by sending it to the tailings dam.

Application of Orica Reagents to Specific Ore Types

Flotation Guidebook

The following ores can be quite complex and vary greatly from one another. Each operation will have a unique processing flowchart and the suite of flotation reagents that is used may be similar or different to what is presented here.

6.1 Iron Sulphide Gold Ores

With these ore types, the gold can be both free and refractory, associated with pyrite, arsenopyrite or pyrrhotite. The sulphide content is generally anywhere from 1% to 4% for low to medium grade ores and from 5 to 10% for high grade ores. The iron sulphide minerals generally need to be activated with copper sulphate before an Orica specialty collector or xanthate addition (but in some instances this may not be required). This is because the iron-xanthate species are only partially hydrophobic, compared with the copper-xanthate species that result from copper activation. After activation, a strong xanthate collector such as PAX can be used as the primary collector. For extra gold and sulphur recovery, additional to what xanthate can provide, DSP 314, DSP 330A and DSP 007 should be tested.

For low to medium grade ores, the frothers DSF 002A, DSF 611, or DSF 802 should be tested. These frothers are particularly efficient in difficult or hard water conditions. For high grade ores, DSF 001A, DSF 004A and DSF 507 should be investigated.

6.2 Copper Ores

When sulphide copper ores contain pyrite as a non-valuable mineral (not containing gold), the pyrite can be depressed by adjusting the pH to between 9 and 12 with lime or by adding sodium metabisulphite. This is completed prior to the addition of the collector. If the pyrite content is very low or insignificant, then flotation of copper may be able to proceed without any pH modification.

Flotation is then carried out with a xanthate or a specific copper (thionocarbamate) collector such as Orica's DSP 009, DSP 032, DSP 110 or DSP 115. The Orica specialty copper collectors can be used alone, without xanthate. They provide fast flotation kinetics and offer the potential to reduce the odour of the final concentrate, if this is found to be a problem with xanthates (refer to section 9). These collectors have the added benefit of being selective against pyrite and arsenic bearing minerals. Oxidised or partially oxidised copper minerals can be activated with NaHS or Na₂S prior to the addition of xanthate or the copper specialty collectors mentioned above.

For low grade copper ores, the frothers DSF 611, DSF 802 and DSF 002A should be tested. For higher grade copper ores, MIBC, DSF 004A, DSF 800 and DSF 507 may be suitable.

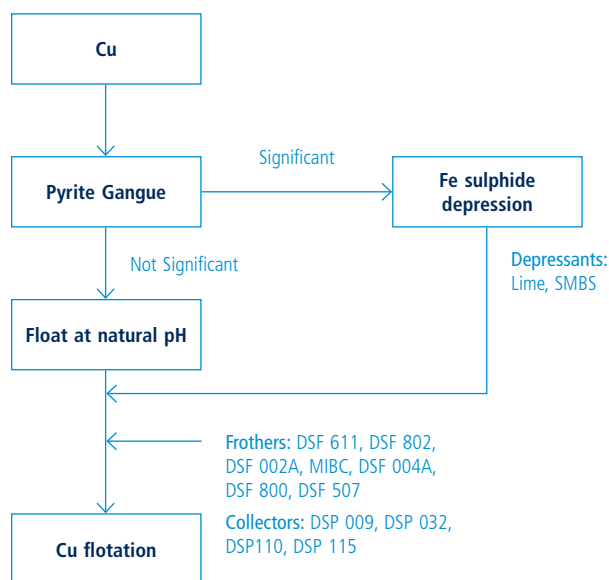


Figure 2. Copper Flotation Flowchart

6.3 Low Grade Copper-Gold Ores

These ores are usually processed on a large scale using a number of different flotation plant designs. There are many types of copper ores in existence. These have been known to include minerals such as copper sulphides, oxides and native copper, as well as sulphides like pyrite, arsenopyrite and molybdenite.

For sulphide-based ores, if lime (and or NaCN) is used for pyrite depression, the copper is floated first at a pH between 9 and 12. If sodium sulphite or sodium metabisulphite is used for pyrite depression then a resultant pH of 6 – 9 may be sufficient without the need to further adjust the pH. A copper specific collector can be added initially to the flash flotation circuit or the rougher feed conditioning tank. The Orica specialty collectors DSP 009, DSP 032, DSP 110 or DSP 115 can be used here as they provide fast copper flotation kinetics along with selectivity against pyrite and arsenopyrite. If the plant is configured to recover copper and gold simultaneously, then the copper-gold collectors DSP 007, DSP 634, DSP 110, DSP 120 or DSP 314 can be tried. If an additional collector is needed for further scavenging of the concentrate, then a xanthate such as PAX may be added to provide additional recovery.

Partially oxidised ores can be activated using NaHS or Na₂S, then floated using the same copper collectors mentioned above. Common depressants such as lime, sodium cyanide, and SMBS have been used for pyrite and arsenopyrite depression. More detailed methods to depress these minerals have been discussed in other publications such as Chander (1998) and Yamamoto (1980).

The best frothers to use for these ore types include DSF 510, DSF 611, DSF 802, DSF 004A and DSF 001A. These are all classed as non-dangerous. DSF 802, DSF 510 and DSF 611 perform exceptionally well in all sorts of water including high salinity and high level of metallic ions in solution. DSF 004A and DSF 001A are known to generate consistent froths over entire rougher/scavenger and cleaner circuits.

6.4 Lead-Zinc Ores

For these ore systems, lead is usually floated first at a pH of 9 to 11, using lime or soda ash to adjust pH and depress pyrite. Soda ash can be used in place of lime if some of the lead is also being found to be depressed. If pyrite is not a problem, lead can be floated at a lower pH without lime or soda ash. The collectors Orica's DSP 330A, SEX or SIPX can be used to provide lead recovery. Sodium cyanide, zinc sulphate or SMBS can be used to provide zinc depression and additional pyrite depression if needed. In most cases the zinc will always need to be depressed. Suitable frothers are MIBC, DSF 800, DSF 004A or DSF 507, especially if the average particle size is less than 75 micron.

The zinc bearing minerals can then be activated with copper sulphate and floated with Orica specialty collectors DSP 009, DSP 032 or xanthates. The Orica specialty collectors have the benefit of being selective against pyrite and can potentially reduce the xanthate odour of the final concentrate, therefore being more environmentally friendly. Dextrin may also be used during zinc flotation to depress carbon, galena and pyrite.

In some instances sufficient separation of lead and zinc using flotation reagents may not be able to be achieved for a number of reasons (including liberation size and mineralogy). In these cases consideration should be given to floating a bulk concentrate then treating further via other methods, for example very fine grinding or reverse flotation. In extreme cases where further treatment is too capital intensive or non-beneficial in terms of extra metal recovery, the bulk concentrate may need to be marketed and sold to a smelter as it is.

6.5 Copper-Zinc Ores

For these ore types the zinc needs to be depressed first while the copper is floated. If pyrite is present, lime can be used to depress it (this will raise the pH). The pH required will depend on the amount of pyrite present, the more pyrite, the higher the pH that will be needed. Lime has the additional benefit of precipitating heavy metal ions that could otherwise activate the zinc. If the copper minerals are partially oxidised so that natural copper activation of the zinc is a problem, then a selective copper collector such DSP 012, DSP 011 or SEX should be tried along with zinc sulphate, SMBS or cyanide to depress the zinc. If the copper mineralogy is not oxidised and the zinc doesn't float so much with the copper, then DSP 009, DSP 110 or DSP 115 should be tested along with the same zinc depressants. After copper flotation, the slurry is conditioned with copper sulphate to activate the zinc bearing sphalerite and a xanthate such as SIPX or SIBX can be used to provide zinc collection and flotation. Alternative specialty zinc collectors that can be tested include DSP 009, DSP 032 and DSP 017. Frothers that are recommended for these ores include MIBC, DSF 510 and DSF 004A.

As discussed in section 6.4, in some instances if the copper and zinc cannot be separated efficiently, it may be more cost effective to produce a bulk concentrate and treat this further or sell it directly to a smelter.

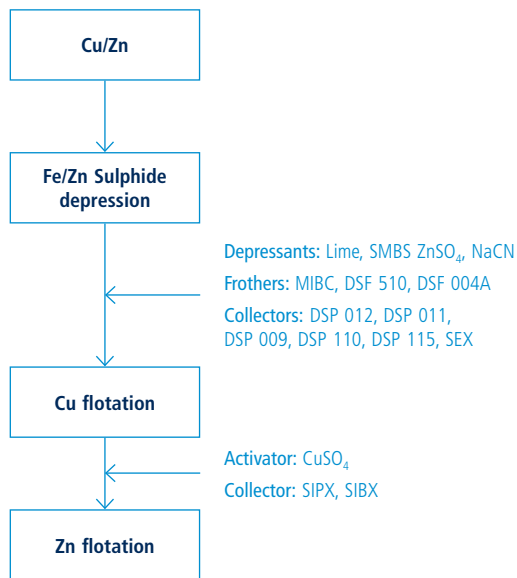


Figure 3. Copper/Zinc Flotation Flowchart

6.6 Copper-Lead-Zinc Ores

These ore types can be floated sequentially to produce separate copper, lead and zinc concentrates. Generally Cu is floated first, followed by Pb then finally Zn. The types of depressants used depend on the minerals present and the degree of activation. Usually SMBS or SO₂, dextrin, sodium cyanide and or zinc sulphate, and lime are added at the start. The SMBS can help to depress any pyrite that is present, and to this end additional lime may not be needed for pyrite depression. Although, if the pyrite contains gold, this may be a valuable credit to the copper concentrate and may need to be floated. Dextrin is added to depress carbon minerals and Pb. Sodium cyanide and or zinc sulphate are added to stop the Zn from floating. A selective collector such as DSP 012, DSP 009 or DSP 115 should be tested in order to produce the copper concentrate. A frother such as, DSF 004A, DSF 510 or MIBC should also be added during conditioning.

The copper tailings can be further conditioned with SMBS, sodium cyanide and or zinc sulphate to further stop the Zn from floating. DSP 330A or SEX can then be added as the collector to float the lead concentrate. If needed, the same frothers used for the copper flotation can be used here. The final stage involves treating the lead tailings with copper sulphate to activate and float the zinc sulphide minerals. The collector should either be DSP 009 or a xanthate (SEX, SIPX or SIBX depending on degree of selectivity required).

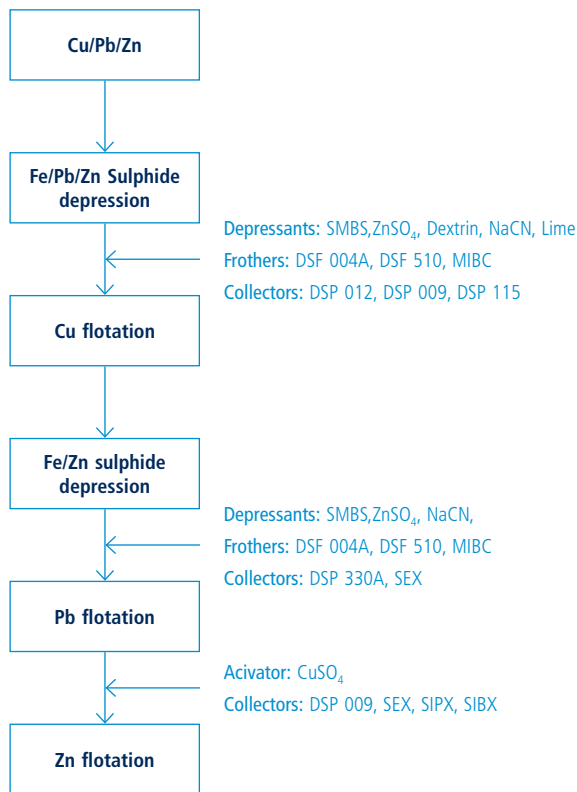


Figure 4. Copper/Lead/Zinc Flotation Flowchart

6.7 Nickel Ores

For nickel sulphide flotation, the main minerals that are involved include pentlandite and pyrrhotite. They usually need to be activated with copper sulphate at natural pH's. Pentlandite and pyrrhotite have the tendency to oxidise easily and are depressed at high pH's (above 9), so care should be taken to avoid oxidation before copper sulphate is added. If oxidation products form on the mineral surfaces, they may form a barrier, preventing successful copper activation (Teague, 1998). Flotation can then be carried out with Orica specialty collectors DSP 115, DSP 413, DSP 432 or alternatively by using a xanthate collectors such as SEX, SIPX or SIBX. Guar gum or CMC can be used to depress gangue material such as talc and serpentine group minerals (eg. lizardite and antigorite). For nickel ores that do not contain significant amounts of pentlandite and pyrrhotite, it may not be necessary to activate with copper sulphate before collector addition, for example some of the nickel ores found north of Kalgoorlie, Western Australia. For clay based medium to high grade nickel ores that contain significant amounts of MgO and silicate gangue material, the Orica frothers DSF 507, DSF 611 and DSF 620 should be tested. For low grade nickel ores such as those found north of Kalgoorlie in Western Australia, DSF 620, DSF 802, DSF 510 and DSF 611 may be suitable.

Planning and Analysis of Flotation Reagent Plant Trials Using the Paired t-test

Flotation Guidebook



Testing a flotation reagent using a plant trial is usually the only way of determining with confidence whether a benefit exists. To this end, it is imperative that the trial is planned in a manner such that a firm conclusion can be reached in the minimum time. There are a few ways that a plant trial can be conducted, but of these, the paired t-test is the most efficient if two flotation reagents are being compared, as outlined by Napier-Munn (1995). This is what is discussed with an example here. During the trial, a paired t-test is applied daily to plant grade and recovery results until a conclusion is reached or until the required number of trials have been completed (see below). Pairs are usually generated sequentially in time (on-off trial), or between parallel circuits. For different operations, the confidence level that is needed to make a conclusion from the t-test will vary, depending on the consequences of the decision, but most would ideally prefer 95% confidence or above. In some cases 90% will be sufficient.

In planning the plant trial one should consider how many days or shifts would be needed to generate enough pairs of data to hopefully reach a conclusion with 95% confidence. This will depend on the magnitude of improvement expected, and the magnitude of experimental 'noise' – the standard deviation of the data. A method of estimating the number of pairs is given (refer to equation 7.0.1). Arrangements must then be made to ensure that the appropriate amount of trial reagent is available on site for the trial.

In the following example (using data listed in the following table), two flotation specialty copper collectors, A (incumbent) and B (new) were compared on a copper flotation circuit. The trial period per reagent was one day or 2 × 12 hour shifts. One day was used as a buffer, in between switching reagents, to stabilise the plant and minimise the effects of either reagent that may still be in the system. The order of switching was also randomised, which is essential. Pairs of data were generated, as shown in the table, together with their corresponding copper grades and recoveries.

Plant Trial Off and On Sequence and Copper Data

Day	Test Status	1 st half of Pair	2 nd half of Pair	Copper Recovery (%)	Copper Grade (%)
1	A				
2	A	1		47.38	2.60
3	B				
4	B		1	50.39	2.83
5	A				
6	A	2		33.76	2.07
7	B				
8	B		2	35.54	1.70
9	B	3		49.22	4.82
10	A				
11	A		3	47.13	5.67
12	A	4		44.41	6.48
13	B				
14	B		4	45.77	5.50
15	A				
16	A	5		33.92	9.51
17	B				
18	B		5	37.15	5.65
19	B	6		70.73	5.28
20	A				
21	A		6	66.34	4.16
22	A	7		60.92	10.62
23	B				
24	B		7	59.69	9.81
25	A				
26	A	8		63.64	6.83
27	B				
28	B		8	62.72	7.54
29	B	9		61.78	3.00
30	A				
31	A		9	61.86	2.72
32	A	10		52.05	3.31
33	B				
34	B		10	51.37	3.56
35	B	11		53.90	2.58
36	A				
37	A		11	47.38	2.53

Once the data have been collated, each reagent's copper recovery can be entered into an Excel spreadsheet side by side for each of the pairs, shown below. The copper grade data can also be done in a similar manner.

Pair	Reagent A (Incumbent) Copper Recovery (%)	Reagent B Trial Copper Recovery (%)
1	47.38	50.39
2	33.76	35.54
3	47.13	49.22
4	44.41	45.77
5	33.92	37.15
6	66.34	70.73
7	60.92	59.69
8	63.64	62.72
9	61.86	61.78
10	52.05	51.37
11	47.38	53.90

Using the Microsoft Excel data analysis function, click on Tools > Data Analysis > t-test: Paired two sample for means, and highlight data presented in the two columns for Reagent A and Reagent B. Excel summarises the main statistics of the t-Test as follows:

t-test: Paired Two Sample for Means

	Reagent A	Reagent B
Mean	50.79909	52.56909
Variance	128.5647	116.1548
Observations	11	11
Pearson Correlation	0.977137	
Hypothesized Mean Difference	0	
df	10	
t Stat	-2.41625	
P(T<=t) one-tail	0.018147	
T Critical one-tail	1.812462	
P(T<=t) two-tail	0.036294	
T Critical two-tail	2.228139	

The null hypothesis for the t-test is that each pair of results is equal ($A_i = B_i$) or that each difference $d_i = 0$ for n pairs. From the 1-tailed P-value above it is shown that the chance of the null hypothesis being true is only 1.8%. This is a low chance and so we would conclude that the null hypothesis is not true and the observed improvement is real (not zero). The confidence with which we can say that the improvement is real:

is calculated as:

$$(1 - 0.018147) \times 100 = 98.2 \%$$

Hence, there is a 98.2 % confidence that the trial reagent B has improved copper recovery, and our best estimate of the magnitude of the increase is the mean difference of 1.77 %. The one-tail statistic is used here because we are looking for an improvement in recovery, ie. we are looking for a change in a particular direction.

A similar process can be used to calculate the confidence in copper grade using the data presented in the table showing the plant trial on and off data. The t-test can be carried out after each pair of data is generated until there is enough confidence in the data to make a decision about which flotation reagent is best. However it is sensible to make an estimate of how many pairs are required before the trial commences. A first approximation can be obtained from equation 7.0.1.

[equation 7.0.1]

$$n = \left(\frac{zs}{D} \right)^2 \text{ (the value of } n \text{ should be rounded up to a whole number)}$$

where: n = number of pairs required
 s = expected standard deviation of the paired differences
 D = expected improvement.
 z = desired confidence level of the test (1-sided).

It is 1.28 for 90% confidence, 1.64 for 95% and 2.33 for 99%. Strictly, this equation defines the number of pairs required to determine the mean difference to within $+ \text{ or } - D$. If we define D as the *expected* difference, and take z as 1-sided, the formula calculates the n needed to ensure that the lower limit of D is greater than zero (ie that there is some improvement).¹ s is the expected standard deviation of the daily differences. As a first approximation s can be taken as the standard deviation of the (daily) data. However in cases where performance varies widely from day to day, the standard deviation of the *differences* will be considerably less than the raw standard deviation. In the example above, the daily standard deviation is about 11% whereas the standard deviation of the differences is only 2.4. If we expect an improvement of 1%, and we want 95% confidence that the difference is not zero, then $n = 326$ if we assume $s = 11$. For the actual standard deviation of the differences of 2.4, $n = 16$. If uncertain of the standard deviation, do a few trials to estimate it.

¹ This is a simplistic treatment of the issue. A full treatment will take into account both the risks of incorrectly concluding that a difference D has occurred, and incorrectly concluding that no change has occurred. Managing both these risks will require considerably more trials than the value estimated from the formula above.



A similar t-test analysis can be carried out on laboratory flotation results. A useful method is one where 2 buckets of plant flotation feed are taken at the same time (1 pair), brought back to the laboratory and tested straight away using one bucket for the incumbent reagent and the other bucket for the new reagent. Successive samples can be planned at set times in the day over a number of days or weeks so that enough pairs of data are available to achieve the required confidence in the results.

Napier-Munn (2008) has outlined alternative data analysis procedures appropriate for cases where a paired trial, or some other formal design, cannot be carried out for practical reasons. However it should be emphasised that the paired trial is always the preferred option when comparing two conditions. It will arrive at the correct answer faster than any other method in nearly all cases.

Xanthate Determination Procedures

Flotation Guidebook



8.1 Solid Xanthate Analysis – Titration Method

- 1 Weigh accurately 2.00 gram of xanthate and dissolve in about 30 mL of deionised (D.I.) water.
- 2 Transfer to a 100 mL volumetric flask and make up to volume with D.I. water (xanthate stock solution).
- 3 Pipette a 25.0 mL aliquot of xanthate solution into a 250 mL conical flask containing 100 mL of water and 3 drops of Methyl Red Indicator.
- 4 Add 0.1 M HCl dropwise until Methyl Red indicator changes (pink).
- 5 Add 50 mL of 0.10 M HCl. (Solution goes milky pink then white then clear).
- 6 Warm flask for 15 minutes at 60 deg. Celsius.
- 7 Cool to room temperature (25 deg. Celsius).
- 8 Add 3 drops of Phenolphthalein indicator.
- 9 Titrate with 0.1M NaOH. Note: The NaOH titre should not drop below 15.40 mL, otherwise the titration will need to be repeated.
- 10 Using equation 8.1.1 and the molecular weight of the respective xanthate (refer to table on next page):

[equation 8.1.1]

$$\% \text{ Available Xanthate} = \frac{(V_{\text{HCl}} \times M_{\text{HCl}}) - (V_{\text{NaOH}} \times M_{\text{NaOH}}) \times MW_{\text{xanthate}} \times V_{\text{stock solution}} \times 100}{(W_{\text{xanthate}} \times 10 \times V_{\text{xanthate aliquot}})}$$

where: MW = molecular weight of the xanthate being analysed (g/mol)
 V = the volume (mL), M is molarity (mol/L),
 W = the weight of xanthate sample (g) and
 V_{HCl} = 50 mL + titrated volume in step 4

Notes:

1. This titration should be performed in a fume hood, due to the evolution of CS_2 when acidifying xanthate solutions.
2. The titration method has a lower limit of 300 ppm xanthate, if using 0.1 M HCl. This method is ideal where the result is expected to be between 1 and 100 %.

Common Xanthate Molecular Weights

	Molecular Weight (g/mol)
Sodium Ethyl Xanthate	144.2
Sodium Isopropyl Xanthate	158.2
Sodium Isobutyl Xanthate	172.3
Sodium Amyl Xanthate	186.2
Potassium Ethyl Xanthate	160.3
Potassium Isopropyl Xanthate	174.3
Potassium Isobutyl Xanthate	188.3
Potassium Amyl Xanthate	202.4
Potassium Hexyl Xanthate	216.3

Example: Two grams of sodium ethyl xanthate has been made up to a 100 mL stock solution. A 25 mL aliquot of this solution has been taken and titrated with 1.58 mL of 0.1 M HCl. For the final titration, 17.42 mL of 0.1 M NaOH was added. Then, using equation 8.1.1:

$$\% \text{ Available Xanthate} = \frac{\left((50 + 1.58) \times 0.1 \right) - (17.42 \times 0.1) \times 144.2 \times 100}{(2 \times 10 \times 25)} = 98.5 \%$$

8.2 Solution Xanthate Analysis – Titration Method

- 1 Pipette a 50.0 mL aliquot of xanthate solution into a 250 mL conical flask containing 100 mL of water and 3 drops of Methyl Red Indicator.
- 2 Add 50 mL of 0.10 M HCl. (Solution goes milky pink then white then clear).
- 3 Warm flask for 15 minutes at 60 deg. Celsius.
- 4 Cool to room temperature (approx. 25 deg. Celsius).
- 5 Add 3 drops of Phenolphthalein indicator.
- 6 Titrate with 0.1M NaOH. Note: The NaOH titre should not drop below 15.40 mL, otherwise the titration will need to be repeated.
- 7 Using equation 8.2.1 and the molecular weight of the respective xanthate:

[equation 8.2.1]

$$\% \text{ Available Xanthate} = \frac{(V_{HCl} \times M_{HCl}) - (V_{NaOH} \times M_{NaOH}) \times MW_{xanthate} \times 100}{(V_{xanthate \text{ aliquot}})}$$

where: MW = molecular weight of the xanthate being analysed (g/mol)

V = volume (mL),

M = molarity (mol/L)

V_{HCl} = 50

8.3 UV-Vis Method

A number of methods for the analysis for sodium ethyl xanthate have been described in detail by Rao (1971). The UV-Vis method is ideal for xanthate analysis in the range of 1 ppm to 20 ppm. It is not usually used for solution strengths in the per cent range (use the method in section 8.2) unless the solutions are diluted down to the range stated above. Note: It is imperative that the background solution matrix used for each standard xanthate solution and the blank solution are the same. In the example below this is site process water. Warm up the UV-Vis spectrophotometer and set wavelength to 301 nm.

- 1 Prepare a fresh standard solution of 100 ppm xanthate in site process water, 0.10 gram in a 100 mL volumetric flask.
- 2 Make up standard solutions of 2 ppm, 5 ppm and 10 ppm xanthate in site process water. Use directions below.

To make up:

2 ppm – pipette 2 mL of 100 ppm xanthate standard into 100 mL volumetric flask and make up to mark with process water.

5 ppm – pipette 5 mL of 100 ppm xanthate standard into 100 mL volumetric flask and make up to mark with process water.

10 ppm – pipette 10 mL of 100 ppm xanthate standard into 100 mL volumetric flask and make up to mark with process water.

- 3 Calibrate UV-Vis spectrophotometer with blank (site process water), 2 ppm, 5 ppm and 10 ppm xanthate solutions. Figure 3 below illustrates a typical relationship between absorbance and solution concentration and shows that absorbance of the xanthate standards should give a straight line that tapers off at higher concentrations.
- 4 Analyse blank and sample solutions and record measurements.

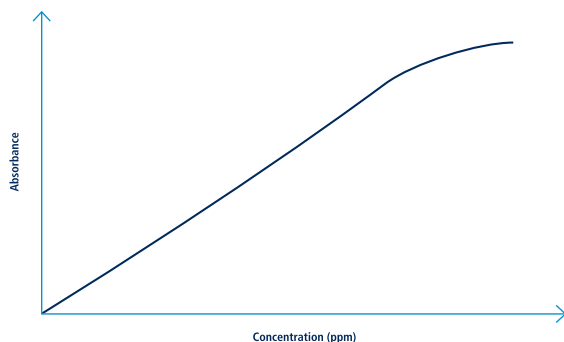


Figure 3. Absorbance of xanthate versus concentration at 301 nm.

Environmental – Concentrate Odour Issues

Flotation Guidebook



The mineral processing industry is currently addressing community issues with respect to odours of metal sulphide/carbonate concentrates, at port storage and ship loading facilities. The decomposition products of xanthate collectors have been noted to include carbon disulphide (CS₂), an alcohol (R-OH), carbonate (CO₃²⁻) and trithiocarbonate (CO₃²⁻) (NICNAS, 1995). The exposure to these hazardous and pungent compounds can occur during manufacture, transport and application in flotation. To reduce risk of exposure to these compounds and reduce their levels in stored concentrates Orica recommends the following:

Recommended Actions:

- Site monitoring of free xanthate in process solutions (see section 8)
- Improved control of xanthate addition in site processes
- Investigation of alternative collectors with a view to optimising the reagent suite (see section 3.4).

The potential benefits that Orica specialty flotation collectors offer include:

- increased chemical stability (before and during use)
- improved selectivity and
- have lower dose rates when compared to equivalent strength xanthate collectors
- reduced levels of odour causing compounds
- No need for mixing! Therefore there is a reduction in labour costs and worker exposure to hazardous decomposition products.

Orica can assist in lab tests and plant trials of specialty flotation reagents, to substitute xanthates with equivalent non-xanthate reagents and to ultimately reduce the odour in sulphide mineral concentrates.

Useful Flotation Calculations

Flotation Guidebook



10.1 Two Product Formula for Plant Recovery

This equation is generally used to calculate plant recoveries when the product weights are not known, but the assays are available.

[equation 10.1.1]

$$\text{Recovery \%} = \frac{100c(f-t)}{f(c-t)}$$

where: c = concentrate grade,
 t = tail grade,
 f = feed grade.

10.2 Two Product Formula for Recovery by Weight and Assay

When the product weights and assays are known, the equation below should always be used.

[equation 10.2.1]

$$\text{Recovery \%} = \frac{100(Cc)}{Cc + Tt}$$

[equation 10.2.2]

Or for multi-concentrate tests:

$$\text{Recovery \%} = \frac{100(C_1c_1 + C_2c_2 + C_3c_3)}{(C_1c_1 + C_2c_2 + C_3c_3 + Tt)}$$

where: C = concentrate weight,
 c = concentrate grade,
 t = tails grade,
 T = tail weight.

An example is given below based on the results of a multi-concentrate laboratory copper flotation test shown in the following table.

Sample	Dry Mass (g)	Assay Cu (%)	Metal Units Cu (g)
Con 1	68.2	16.90	11.53
Con 2	31.3	8.44	2.64
Con 3	20.5	4.33	0.89
Tail	1880.0	0.05	0.94

After the dry weights and assays have been received, the first step is to calculate the metal units (grams of Cu) contained in each sample by multiplying the assay % Cu by the dry mass.

Then from equation 10.2.2 above:

$$\text{Recovery} = \frac{100(11.53 + 2.64 + 0.89)}{(11.53 + 2.64 + 0.89 + 0.94)} = 94.1 \%$$

10.3 % Solids

If the SG for the ore is known then:

[equation 10.3.1]

$$\% \text{ Solids by Mass of a Flotation Slurry} = \frac{SG_{dry\ solids} (SG_{pulp} - SG_{liquor})}{SG_{pulp} (SG_{dry\ solids} - SG_{liquor})} \times 100$$

Pulp SG can be determined by weighing one litre of the pulp (in grams) in a 1 litre measuring cylinder and then dividing the result by 1000.

10.4 Mass of Solids in a Flotation Cell

If the pulp SG, solids SG and process water SG are known then:

[equation 10.4.1]

$$\text{Mass of solids in cell (kg)} = \frac{V \times SG_{solid} (SG_{pulp} - SG_{liquor})}{(SG_{solid} - SG_{liquor})}$$

where: V = cell volume (L)
 SG_{solid} = solid SG (g/cm³)
 SG_{pulp} = slurry SG (g/cm³)
 SG_{liquor} = process water SG (g/cm³)

10.5 Solids Mass and Water Calculation for Laboratory Flotation Tests

The following equations can be used to calculate the mass of ore and water needed to make up the required % solids slurry for a known flotation cell volume. If the ore specific gravity (SG), the required % solids and the cell volume are known, then:

[equation 10.5.1]

$$M_{water} = V - \frac{M_{ore}}{SG_{ore}}$$

[equation 10.5.2]

$$\% Solids = 100 \times \frac{M_{ore}}{M_{ore} + M_{water}}$$

where: V = cell volume (mL)
 SG = specific gravity of ore (g/cm³)
 M_{ore} = mass of ore required (g)
 M_{water} = mass of water (g) required for a particular % solids.

As an example, if the ore SG is known to be 2.8, the flotation cell volume is 3 litres and the % solids required is 45, then:

From equation [10.5.2]:

$$M_{ore} + M_{water} = \frac{M_{ore}}{0.45}$$

$$M_{water} = 1.222 M_{ore}$$

Substituting this result into equation [10.5.1] gives:

$$3000 - \frac{M_{ore}}{2.8} = 1.222 M_{water}$$

$$4.422 M_{ore} = 8400$$

$$M_{ore} = 1899.6 \text{ g}$$

$$\text{Since } M_{water} = 1.222 M_{ore}, \text{ then } M_{water} = 2321 \text{ g}$$

10.6 Reagent Usage Conversion (mL per minute to gram per tonne)

For frother and collectors that are used without dilution:

[equation 10.6.1]

$$\frac{(F \times SG \times 60)}{T} = \text{grams reagent per tonne of ore}$$

where: SG = reagent specific gravity (g/cm³)
 F = reagent flowrate (mL/min)
 T = the throughput (tph)

10.7 Residence Time

The total time that pulp being fed through a bank of flotation cells of known volume at a given rate, occupies the specific cell bank.

[equation 10.7.1]

$$\text{Residence Time (Hours)} = \frac{V}{Q_t}$$

where: V = total cell volume in m³.
 Q_t = volumetric flowrate of slurry passing through the flotation cells (m³/hour)

10.8 Laboratory Flotation Testing Tips

Conversion

1 g/t = 1 ppm

1% = 10 000 ppm

Dose Rate (for a 1kg float test)

1 ml of 1% solution concentration = 10 g/t

10 ml of 1% solution concentration = 100 g/t

1 ml of 10% solution concentration = 100 g/t

10 µL of 100% solution concentration = 10 g/t

- When adding Orica specialty collectors and frothers to the pulp, use microlitre syringes to add them neat.
For flotation testing of 1kg of solid:
10 µL of neat solution = a dosage of 10 gram/tonne
- Add the specialty collectors and frothers in the same cell position each time for consistency. Depress the syringe plunger when the needle is slightly beneath the pulp surface, but be careful not to get any slurry in the syringe because they can become blocked easily.

- Try to be as accurate and consistent as possible when measuring amounts of specialty collectors and frothers with the microlitre syringes. Expel any air bubbles that may be present in the syringe before discharging as this can affect the accuracy of the dosage. Because the reagents are concentrated, any differences in measurements between tests can have an effect on the final testwork results.
- For consistency during concentrate collection, measure your scrape rate and maintain the same rate throughout the test period. A good starting point is to scrape one entire cell cross-section every 10 or 15 seconds.
- The following froth scraper design as outlined by Teague (1998) is recommended for top-driven laboratory flotation machines where the impeller usually gets in the way of froth scraping. Froth scrapers can be designed and fabricated from stainless steel plate and vinyl so that they move simultaneously on each side of the cell, whilst taking a full cross-section of the froth with each stroke. The vinyl is attached to the stainless steel plate so that the scrapers have the flexibility to bend around the impeller and remove any concentrate adhering to it. The froth height in the cell decreases with time as more and more froth is removed to the concentrate tray, but because the scraping depth is limited by the dimensions of the scrapers and the top edge of the cell, this variable is constantly maintained throughout each test and each test is therefore consistent. Figure 4 shows a schematic diagram of the scrapers. The final dimensions of the scrapers should be determined by experimenting with froth heights and cell volumes during a standard laboratory flotation test. Two scrapers are required to be used in a test.

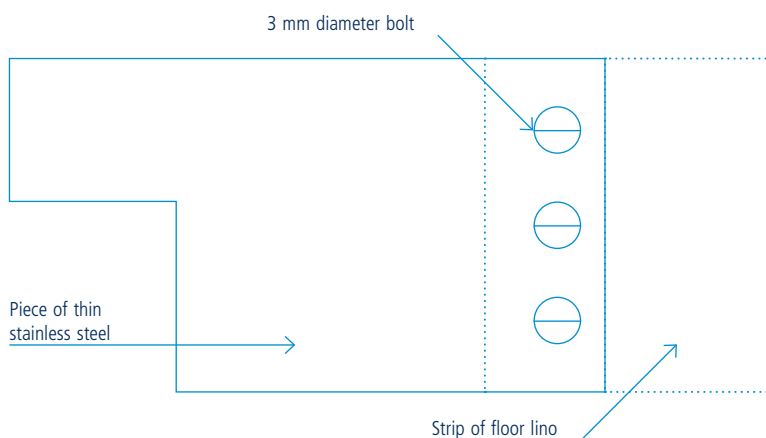


Figure 4. Schematic of flotation scrapers.

10.9 Standard Unit Conversions

Length

1 millimetre (mm)	= 1 000 micron (μm)	
1 centimetre (cm)	= 10 mm	
1 metre (m)	= 100 cm	= 1 000 mm
1 kilometre (km)	= 1 000 m	
1 km	= 0.621 miles	
1 mile	= 1.609 km	
1 inch	= 25.4 mm	= 2.54 cm
1 foot	= 12 inch	= 0.3048 m

Area

1 square metre (m^2)	= 10 000 square centimetres (cm^2)	
1 m^2	= 10.76 square feet (ft^2)	= 1 550 square inches (in^2)
1 ft^2	= 0.0929 m^2	
1 ft^2	= 144 in^2	
1 acre	= 43 560 ft^2	
1 hectare	= 10 000 m^2	
1 hectare	= 2.471 acre	

Mass

1 kilogram (kg)	= 1 000 grams (g)	
1 kg	= 2.205 pounds (lb)	
1000 kg	= 1 <i>metric tonne</i> (t)	
1 lb	= 454 g	
1 ounce	= 28.35 g	
1 troy ounce	= 31.1035 g	
1 troy ounce	= 20 pennyweights	
1 short ton (US)	= 907.18 kg	



Volume

1 millilitre (mL)	= 1000 microlitres (µL)	
1 litre (L)	= 1000 mL	
1 cubic metre (m ³)	= 10 ⁶ cm ³	= 1000 L (at SG 1)
1 US gallon	= 3.785 L	
1 Imperial gallon	= 4.546 L	
1 L	= 0.264 US gallon	
1 cubic ft	= 28.32 L	

Temperature

1 degree centigrade	= (°C × 9/5) + 32 degrees Fahrenheit
---------------------	--------------------------------------

Pressure

1 bar	= 10 ⁵ Pascal (Pa)	
1 pound per square inch (PSI)	= 6894.76 Pa	
1 atmosphere (atm)	= 101 325 Pa	= 101.3 kiloPascals (kPa)

Common Minerals and Properties

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Name	Composition %		Specific Gravity
Antigorite	H ₄ Mg ₃ Si ₂ O ₉	(SiO ₂ 44.1, MgO 43, H ₂ O 12.9)	2.62
Argentite	Ag ₂ S	(Ag 87.1, S 12.9)	7.2–7.4
Arsenopyrite	FeAsS	(Fe 34.3, As 46, S 19.7)	6.0
Bornite	Cu ₅ FeS ₄	(Cu 63.3, Fe 11.1, S 25.6)	5.1
Cassiterite	SnO ₂	(Sn 78.6, O 21.4)	6.8–7.1
Chalcocite	Cu ₂ S	(Cu 79.8, S 20.2)	5.5–5.8
Chalcopyrite	CuFeS ₂	(Cu 34.5, Fe 30.5, S 35)	4.1–4.3
Chromite	FeCr ₂ O ₄	(Fe 24.9, 46.5, 28.6)	4.1–4.9
Chrysocolla	CuSiO ₃ ·2H ₂ O	(CuO 45.2, SiO ₂ 34.3, H ₂ O 20.5)	2.0–2.24
Covellite	CuS	(Cu 66.4, S 33.6)	4.6
Enargite	Cu ₃ (As,Sb)S ₄	(Cu 48.3, As 19.1, S 32.6)	4.45
Fluorite	CaF ₂	(Ca 51.1, F 48.9)	3.18
Galena	PbS	(Pb 86.6, S 13.4)	7.58
Gold	Au		19.33
Lizardite	H ₄ Mg ₃ Si ₂ O ₉	(SiO ₂ 44.1, MgO 43, H ₂ O 12.9)	2.57
Malachite	Cu ₂ (OH) ₂ CO ₃	(CO ₂ 19.9, CuO 71.9, H ₂ O 8.2)	3.6–4.1
Millerite	NiS	(Ni 64.7, S 35.3)	5.3–5.5
Molybdenite	MoS ₂	(Mo 60, S 40)	4.6–4.7
Pentlandite	(Fe,Ni) ₉ S ₈	(Fe 42, S 36, Ni 22)	4.6–5.0
Pyrite	FeS ₂	(Fe 46.6, S 53.4)	4.8–5.0
Pyrrhotite	Fe ₇ S ₈	(Fe 60.4, S 39.6)	4.6–4.7
Quartz	SiO ₂	(Si 46.7, O 53.3)	2.65
Serpentine	H ₄ Mg ₃ Si ₂ O ₉	(SiO ₂ 44.1, MgO 43, H ₂ O 12.9)	2.5–2.65
Sphalerite	ZnS	(Zn 67, S 33)	3.9–4.1
Stibnite	Sb ₂ S ₃	(Sb 71.7, S 28.3)	4.6
Talc	Mg ₃ Si ₄ O ₁₀ (OH) ₂	(SiO ₂ 63.5 MgO 31.7 H ₂ O 4.8)	2.5–2.0
Tennantite	(Cu,Fe) ₁₂ (Sb,As) ₄ S ₁₂		4.6–5.1

Particle Size Conversions

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12.1 Screen Size Conversions

Standard	Tyler Mesh
1.68 mm	10
1.20 mm	16
840 micron	20
600 micron	28
425 micron	35
300 micron	48
212 micron	65
150 micron	100
106 micron	150
75 micron	200
53 micron	270
45 micron	325
38 micron	400

12.2 Cyclosizer Cone Size Conversion

At standard conditions of Water Flowrate = 11.6 Litres/min,
 Water Temperature = 20°C, Particle SG = 2.65 g/cm³
 and running time of cyclosizer is infinite.

Cyclone No.	Equivalent Stokesian Diameter (Microns)		
	S.G. = 2.7 (Quartz)	S.G. = 5.2 (Pyrite)	S.G. = 7.5 (Galena)
C1	44	27	22
C2	35	22	18
C3	23	14	11
C4	15	9	8
C5	9	6	5

Cyclosizer Operating Instructions

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The Cyclosizer is a laboratory precision apparatus for the rapid and accurate determination of particle size distribution within the sub-sieve range. It is manufactured for worldwide distribution by Metcon Laboratories, under license from Weir Minerals Australia Ltd. Particles are separated according to their Stokesian settling characteristics by a principle based on the well known hydraulic cyclone principle. The effective separation range is 50 to 8 micron for material of specific gravity similar to quartz (S.G. 2.7) but the lower limit may extend down to 4 microns for particles of high specific gravity, for example galena, S.G. 7.5 (Cyclosizer Operating Manual, 1997). In this instance, a gold particle of approximately 15 micron particle would collect in cyclone 1 along with 44 micron quartz particles (refer to section 12). If three different specific gravity materials were being fed through the Cyclosizer at any one time, then in effect, three different sizings would be taking place.



Figure 5. Cyclosizer M14 model with digital flowmeter (Metcon Laboratories, 2008).

Not many changes have been made to the Cyclosizer design over the years although model numbers have changed to reflect changes to parts suppliers. The previous model update was in 2001 with the M13. The main difference in the M14 model is the change from a mechanical rotameter to a digital flowmeter (Metcon Laboratories, 2008). This model is shown in figure 5 and the operating instructions follow.

Preparation of the Test Sample

- 1 Dry test samples need to be weighed to record a dry weight and then pulped with 50 to 150 mL of water to which a little wetting agent can be added, such as a detergent. The pulped sample should be agitated enough to ensure thorough wetting of the particles.
- 2 All samples to be cyclosized should be wet-screened at 75 microns for materials up to a specific gravity of 4.0 and at 53 microns for materials with a specific gravity higher than 4.0. The undersize material is washed through into a 3 litre beaker and is allowed to settle for 1 hour. After settling, the liquor can be carefully syphoned or decanted until the volume remaining is approximately 200 mL. This volume containing the settled solids can then be transferred to the sample container for cyclosizing.

Test Procedure

When the sample has been prepared as described above, select an elutriating flowrate (normally 11.6 L/min) and determine the millimetre reading of the rotameter which corresponds to this selected valve. Then proceed as follows:

- 1 With the pump 'off' remove the sample container from its holder by turning the container until one of the metal sides is facing you and pull straight upwards.
- 2 Open fully the valve on the sample container and empty out any water. Stand it inverted on the hand wheel of the valve.
- 3 Pour the test sample into the container and, using a wash bottle, wash the remaining solids out of the beaker into the container.
- 4 Continue to fill the sample container with clean water until the level is about half way up the outside taper. Screw up the valve of the sample container until it is closed. At this stage the sample should be sealed within the container and all air eliminated.
- 5 With the sample container valve closed, return it to the holder on the Cyclosizer by a reversal of step 1. It is imperative that you ensure that the sample container is correctly fitted in the holder and that a glass side is facing you before proceeding further.
- 6 Turn on the water supply to the constant head tank and wait until the tank is full, i.e. until the float valve has closed.
- 7 Ensure that the control valve is closed and switch the pump on at the control panel.
- 8 Open the control valve slowly and allow the air to be expelled from the pipe work, then open the control valve fully.
- 9 Starting from No. 1 cyclone, bleed the air from the cyclones by opening the apex valves one at a time or alternatively close both the apex valve and the control valve and allow the residual air to collect in the apex chamber, then open both valves fully and the air will be expelled.
- 10 With the control valve fully open, set the timer to 5 minutes and open the sample container valve slowly.
- 11 Manually regulate the container valve so that by the time the alarm sounds, the sample has been completely discharged into the stream. Avoid sudden surges from the sample container.
- 12 After the 5 minutes has elapsed, close the control valve until the flowmeter indicates the required elutriating flow. Set the timer to the required elutriating time.

- 13 When the alarm indicates the elutriation time has elapsed, cancel the alarm and turn the control valve to full flow.
- 14 Starting with No. 5 cyclone, pull the plastic tube from the drain manifold, open the apex valve and discharge the solids from the apex chamber into a 1000 mL beaker.
- 15 Close No. 5 discharge valve and proceed to No. 4 cyclone and so on in turn to the other cyclones. Make a note of the water temperature.
- 16 Allow the beakers to stand for at least 20 minutes and decant the excess water.
- 17 For final recovery and weighing, the sized fractions may be filtered on a tared paper and dried, or simply transferred to evaporating dishes for drying without filtering.
- 18 Calculate the percentage passing No. 5 cyclone as the difference between the initial weight and the sum of the weights of the separate fractions.

Note: If desired, a sample of fine solids passing the last cyclone can be recovered by collecting the waste water and settling. This can be done in plastic drums. Some 80 to 90% of the fine material can be recovered by collecting the water over the first ten minutes of operation following the opening of the sample container valve. Do not allow the pump to run for any length of time with the control valve fully shut off. It could cause heat to build up in the pump and hence risk damage.

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Periodic Table of the Elements

1									
1 H 1.01	2								
3 Li 6.94	4 Be 9.01			1 H 1.008	Atomic number Element		Atomic weight		
11 Na 22.99	12 Mg 24.31								
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.67	23 V 50.94	24 Cr 52.0	25 Mn 54.94	26 Fe 55.84	27 Co 58.93	
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 97.91	44 Ru 101.07	45 Rh 102.91	
55 Cs 132.91	56 Ba 137.33	57–71	72 Hf 178.49	73 Ta 180.94	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	
87 Fr (223)	88 Ra (226)	89–103	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	
		57 La 138.91 Lanthanoids	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm 144.91	62 Sm 150.36	63 Eu 151.96	
		89 Ac 227.03 Actinoids	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	

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