APPLICATION OF HALLIMOND TUBE FOR FLOTABILITY STUDY OF MAGNETITE

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APPLICATION OF HALLIMOND TUBE FOR FLOTABILITY STUDY OF MAGNETITE

by

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In the name of Allah

Most Gracious Most Merciful

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APLIKASI TIUB HALLIMOND UNTUK KAJIAN KEBOLEHALIRAN MAGNETIT

ABSTRAK

Projek ini memberi tumpuan kepada mengkaji kesan parameter yang berbeza-beza ke atas pemulihan magnetit. Sebagai contoh, pH, masa penyaman, dos pengumpul, masa pengapungan dan asid maleik sebagai pengumpul adalah parameter yang telah dikaji. Parameter optimum, yang memberikan pemulihan maksimum pada setiap pembolehubah ditentukan satu eksperimen telah dilakukan. Eksperimen dijalankan dalam tiub Hallimond yang diubah suai dengan menggunakan sampel yang mempunyai 96.81 peratus oksida besi. Asid oleik dan asid maleik digunakan sebagai pengumpul. Berdasarkan keputusan yang diperoleh, ia menunjukkan bahawa asid oleik adalah pengumpul yang cekap untuk pengapungan magnetit. Magnetit terapung lebih baik pada fasa alkali dengan pH 11. Selain daripada itu, untuk masa penyaman yang optimum, ia menunjukkan bahawa 8 minit adalah masa terbaik untuk pengapungan magnetit. Bagi dos pengumpul, keputusan menunjukkan dos pengumpul terbaik ialah 300 g/t dengan pemulihan maksimum. Tambahan pula, masa pengapungan selama 8 minit memberikan pemulihan maksimum magnetit. Pengumpul yang berbeza telah digunakan iaitu asid maleik untuk menyiasat prestasi dan menunjukkan bahawa asid maleik mempunyai pemulihan yang kurang berbanding asid oleik dengan peratusan pemulihan yang berbeza iaitu 0.38%.

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ABSTRACT

This project focused on studying the effect of varied parameters on recovery of magnetite. For example, pH, conditioning time, collector dosage, flotation time and maleic acid as a collector are the parameters that been study for. The optimum parameter, which gave the maximum recovery on each variable was determined. The experiment was conducted in a Hallimond tube by using sample of having 96.81% of iron oxide. Oleic acid and maleic acid were employed as collector. Based on the results obtained, it showed that oleic acid is the efficient collector for flotation of magnetite. Magnetite float better on the alkaline phase with pH of 11. Other than that, for best conditioning time, it showed that 8 minutes is the ideal time for flotation of magnetite. For the collector dosage, the results showed that the best dosage of collector was 300 g/t with maximum recovery. Furthermore, the flotation time of 8 min gave the maximum recovery of magnetite. Different collector was used which is maleic acid to investigate the performance and it showed that maleic acid has less recovery compared to oleic acid with the recovery of 39.63%.

CHAPTER 1

INTRODUCTION

1.1 Research background

Few metals or minerals exist in complicated aggregates of up to twenty distinct minerals, only one or two of which are valuable. Among the many thousand minerals that make up the earth's crust, there are around 200 of “value" minerals. As a result, the number of mineral combinations that might occur with a valuable component is quite enormous, and any deposit (ore) having essentially the same precious minerals will differ significantly from all others. As a result, the optimum separation procedure for a certain ore depends on its entire mineralogy rather than just the nature of the precious components (Shergold, 1984).

Mineral processing is the first process once ore is extracted from the mine. Mineral processing is a process that comprises ore pre-treatment, milling, and ore dressing and mechanically extracts ore mineral grains from the gangue (low value) minerals that surround them to generate a concentration of precious minerals. This separation can be performed physically via utilizing gravity, electrostatic separation, and magnetic separation, or chemically by using froth flotation, leaching, and electrowinning.

Froth flotation is a usually applied metallurgical process that is applicable in a range of sectors including such mineral processing and wastewater treatment. This revolutionary technical discovery was initially applied in mineral processing in the early twentieth century (Mondal et al., 2021).

1.2 Problem Statement

Iron ore is the principal source of iron for the iron and steel industries around the world. It is thus necessary for the manufacturing of steel, for the maintenance of a strong industrial basis. Almost all iron ore (98 percent) is utilised to make steel. Magnetite is one of the iron ore which is useful for steel making in industry.

Various types of collectors are employed in the flotation process, depending on their qualities. Because most collectors are not particular, efficient separation necessitates understanding of how magnetite reacts to different types of collectors.

Previous research shows that increasing in collector’s dosage will give expected result in the collection (pulp) zone. Some of them did different parameters such as pH values that potentially increase the concentration of magnetite in the floatation test. In this dissertation, some parameters have been chosen to carry out this experiment to test the floatability of magnetite.

The bulk concentration of the important minerals can be recovered through the development of the flotation process, giving industry a valuable resource at a reasonable cost. Therefore, the objective of this flotation invention is to provide a method for concentrating magnetite.

1.3 Objectives

The main objectives of the research are:

1. To characterize the magnetite.
2. To investigate the floatability of magnetite mineral using Hallimond tube.
3. To determine the optimum parameters used in the floatation process of magnetite by varying conditioning time, pH, collector's dosage, flotation time and type of collector.

1.4 Scope of work

This project is to determine the selectivity separation of magnetite with variation of parameters by froth flotation technique. The main collector for this study is oleic acid which is fatty acid that is widely used in flotation of iron ore for centuries. Maleic acid is infrequently used in iron ore flotation. Hence, in this project will study the effectiveness of maleic acid in flotation of magnetite. All data analysis will be used in analysing the optimum parameters for flotation of magnetite.

The experiment was carried out using Hallimond tube. As for the Hallimond tube, the sample needs to be grinded to a very small particles as the concept of Hallimond tube is micro flotation. Mineral characterisation analysis also needs to be carried out to prove that the sample is pure magnetite and to determine the chemical and mineral composition in magnetite by using XRF, XRD and optical microscope.

By doing this project, the flotation of magnetite can easily be done by focusing on the best parameters that has been decided.

1.5 Thesis outline

This thesis is divided into five sections, the first of which contains a general introduction to the research, the study area, and the study's goal. The goal of the kinetics of froth flotation of magnetite in the industry will also be explained in this chapter.

The literature study in Chapter Two will focus on how froth flotation of magnetite is done in the industry.

The methods of the research study will be discussed in Chapter Three, which will involve the preparation of the sample for sampling and sieving. This chapter also included the experimental work with the Hallimond tube and the previously mentioned parameters. Mineral identification was determined using XRD, while chemical composition was determined using XRF.

In Chapter Four, the experimental work's results and debate were discussed, and in Chapter Five, the experimental work's conclusion and recommendations were offered.

CHAPTER 2

LITERATURE REVIEW

2.1 Geology and Mineralogy of Magnetite

Iron is the third most prevalent mineral in the earth's crust, and it may be found in a variety of chemical forms in various ore deposits. In comparison to sulphides and carbonates, iron oxides are the most abundantly occurring deposits (Pattanaik and Venugopal, 2018).

Magnetite (Fe_3O_4) is found throughout the earth's crust and sediments as a main or secondary mineral in igneous, metamorphic, and sedimentary rocks, as well as sediments and soils. (B.M. Moskowitz, 2015).

Magnetite is a common iron ore. It may be found as an accessory mineral in most igneous rocks. Through magmatic segregation, one of the main elements in certain kinds can produce massive ore bodies. These bodies are frequently titaniferous. Most typically linked with crystalline metamorphic rocks, but also with rocks rich in ferromagnesian minerals such as diorite, gabbro, and peridotite. It also occurs in massive beds and lenses, as well as in ancient metamorphic rocks. Found on the seashore's dark sands. It appears as thin plates and dendritic growths between mica plates. Emery is a substance that is frequently connected with corundum. (Science, 2019).

Magnetite micro-scale crystals, both natural and synthetic, with a metallic sheen and an opaque jet-black colour. Magnetite has a density of 5.18 g/cm3, which is slightly lower than reddish-brown hematite (-Fe_2O_3; 5.26 g/cm3) and somewhat higher than yellowish orange ferrihydrite (-FeOOH; 4.26 g/cm3); pure iron (-Fe) has a density of 7.87 g/cm3. Magnetite particles have a hardness of 5.5 at room temperature, which is the same as glass.

Bragg and Nishikawa, 1915 found that, the primary features of magnetite's structure were discovered; this was one of the first mineral structures to which X-ray diffraction was used. The structure is similar to that of an inverted spinel (Hill et al., 1979). Magnetite features a face-cantered cubic unit cell made up of 32 O2-ions that are cubically tightly packed along the [111]. The unit cell edge length is a= 0.839 nm. There are eight formula units per unit cell (Cornell and Schwertmann, 1996).

The structure consists of octahedral and mixed tetrahedral/octahedral layers stacked along [111] (Figure 2.1). Figure 2.2 shows the sequence of Fe- and O-layers and a section of this structure with three octahedra and two tetrahedra is depicted in Figure 2.3.

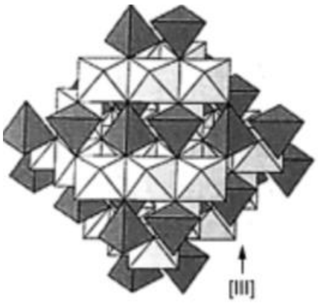


Figure 2.1: Polyhedral model with alternating octahedra and tetrahedra-octahedra layers (Cornell & Schwertmann, 2003)

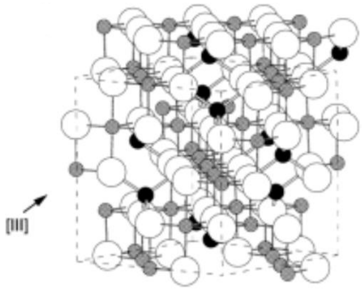


Figure 2.2: Ball-and-stick model. Unit cell outline (Cornell & Schwertmann, 2003)

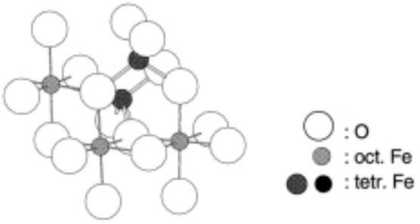


Figure 2.3: Ball-and-stick model of the arrangement of octahedra and tetrahedra

(Cornell & Schwertmann, 2003)

Table 2.1: Typical Characteristics of Magnetite (Science, 2019)

Chemical Formula	Magnetite (Fe_3O_4)
Colour	Black, grey with brownish tint in reflected sun
Streak	Black
Lustre	Metallic
Diaphaneity	Opaque
Mohs Hardness	5.5 - 6.5
Specific Gravity	5.17 – 5.18
Diagnostic Properties	Dissolves slowly in hydrochloric acid
Crystal System	Isometric

Table 2.2: Optical Properties of Magnetite (Science, 2019)

Type	Isotropic
RI values	n = 2.42
Twinning	As both and composition plane, the spinel law, as contract twins
Birefringence	Isotropic minerals have no birefringence
Relief	Very high
Crystal system	Isometric

2.2 History of Flotation

Iron ore flotation began with direct flotation of iron oxides using anionic collectors but has since been largely replaced by reverse cationic flotation, which has become the most used flotation route in the iron ore sector. Because desliming is not required in reverse anionic flotation circuits, the successful implementation of reverse anionic flotation in China's iron ore industry in recent years provides a good opportunity to decrease costs while increasing iron recovery. Column flotation cells have been used in a few iron ore operations, mostly in Brazil. Various advantages of column flotation cells have been revealed, but a negative report on iron ore column flotation was also discovered in the literature (Ma, 2012).

2.3 Principal of Flotation

Flotation is a physicochemical separation method that takes use of the differences in surface characteristics between precious minerals and undesired gangue minerals. The theory of froth flotation is complicated, including three phases (solids, water, and froth) as well as several subprocesses and interactions, and it is not fully understood.

The communication between the mineral surface, the solution, and the reagents used, such as frothers, collectors, and depressants, is at the heart of froth flotation. Collectors as well as depressants are used to alter the mineral surface's hydrophobicity, which helps determine its floatability. These interactions are investigated using three main methods: adsorption density, zeta potential, and microflotation. These methods define adsorption behaviour and provide information for predicting optimal bench scale flotation conditions. The sections that follow will bring to light the fundamental methods that lead up to bench scale flotation (Rutledge, 2016).

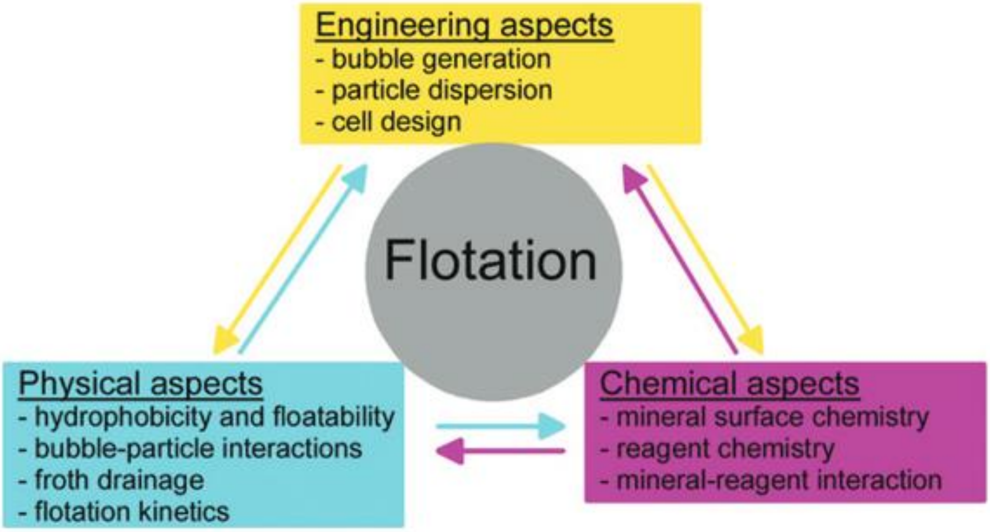


Figure 2.4: Aspects needed for understanding of flotation process

(Nguyen, 2013)

In froth flotation: a century of innovation by Fuerstenau, Jameson & Yoon, 2009 stated that so far, the focus has been on the collision, attachment, and disconnection of particles in a flotation cell's pulp phase. Given the general consideration about particle production from the cell, the froth phase must also be considered. The pulp-froth interface is the first barrier particles must overcome on their way to the overflow lip. Bubbles transporting particles will rise toward the interface with a net upward velocity with same sequence as the bubble-particle aggregate's terminal velocity. While entering the froth, the bubbles slow down in a short period of time at the interface. Some large particles are likely to perish during the transition.

The most essential process is the attachment of precious minerals to air bubbles, which accounts for the bulk of particles recovered to the concentrate. Although true flotation is the major process for valuable mineral recovery, the separation efficiency between valuable mineral and gangue is also affected by entrainment and physical entrapment. True flotation takes use of variances in the physicochemical surface characteristics of mineral particles. Such disparities in surface qualities between minerals within the flotation pulp become obvious after reagent treatment, and for flotation to occur, an air bubble must be able to attach itself to a particle and raise it to the water surface. (Wills *et al.*, 2006).

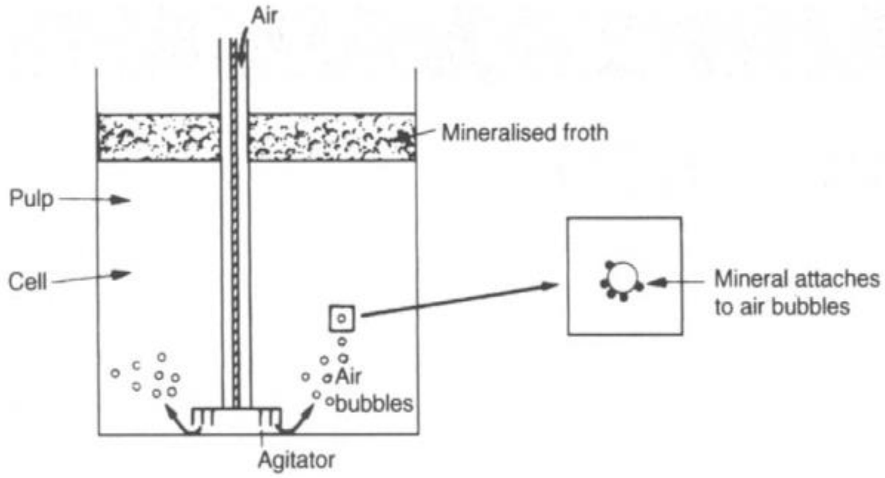


Figure 2.5: Principle of froth flotation (Wills *et al.*, 2006)

The particles that have connected air bubbles are subsequently transported to the surface and ejected, whilst the particles that are thoroughly soaked remain in the liquid phase. Because chemical treatments may be used to selectively change mineral surfaces so that they have the requisite characteristics for the separation, froth flotation can be applied to a wide range of mineral separations. It is currently used for a wide range of applications, including separating sulphide minerals from silica gangue (and other sulphide minerals); separating potassium chloride (sylvite) from sodium chloride (halite); separating coal from ash-forming minerals; removing silicate minerals from iron ores; separating phosphate minerals from silicates; and even non-mineral applications like de-ink recycled newsprint. It is especially effective for treating fine-grained ores that are unsuitable for gravity concentration (Kawatra, 2021).

The differential in wettability of various minerals is the basis of froth flotation. Water-wettable (hydrophilic) particles are distinguished from water-repellent particles (hydrophobic). When a combination of hydrophobic and hydrophilic particles is suspended in water and bubbled with air, the hydrophobic particles prefer to stick to the air bubbles and float to the surface. The surface froth layer will then be highly laden with the hydrophobic material and may be extracted as a separate product. Because hydrophilic particles have a lower proclivity to connect to air bubbles, they will remain in suspension and be washed away (Whelan and Brown, 1956).

Particles can be inherently hydrophobic or have their hydrophobicity produced by chemical treatments. Hydrocarbons and non-polar solids such as elemental sulphur are naturally hydrophobic compounds. Because it is largely made up of hydrocarbons, coal is an excellent example of a naturally hydrophobic substance. Chemical treatments to make a surface hydrophobic are essentially ways for covering a particle surface selectively with a monolayer of non-polar oil (Kawatra, 2021).

Figure 2.6 depicts a typical dependence of flotation recovery on particle size. Mineral recovery by flotation is most impactful in the 10-200mm size range. The relatively poor response of fine and coarse particle fractions in many cases is a major issue in flotation. Both large and small particle recovery suffer a decrease. The reasons for the decrease in flotation rate and recovery at the fine and coarse ends of the particle size distribution are distinctive. The relatively slow flotation rate of fine particles is generally attributed to the reduction in particle-bubble collision and attachment efficiency. The very poor recovery of coarse particles is thought to be caused by disruption of particle-bubble aggregates in excessively turbulent zones of flotation cells, resulting in an increase in particle-bubble detachment efficiency.

Fine and coarse particles require different hydrodynamic conditions. The bubble-particle collision and attachment processes control fine particle flotation, which should be operated at higher power input to produce smaller bubbles at moderate to high agitation. The bubble-particle separation process controls coarse particle flotation, which requires turbulence intensity that only ensures complete particle suspension. The advantage of using smaller bubbles for coarse or high-density particles is diminished, and high turbulence is detrimental (Nguyen, 2013).

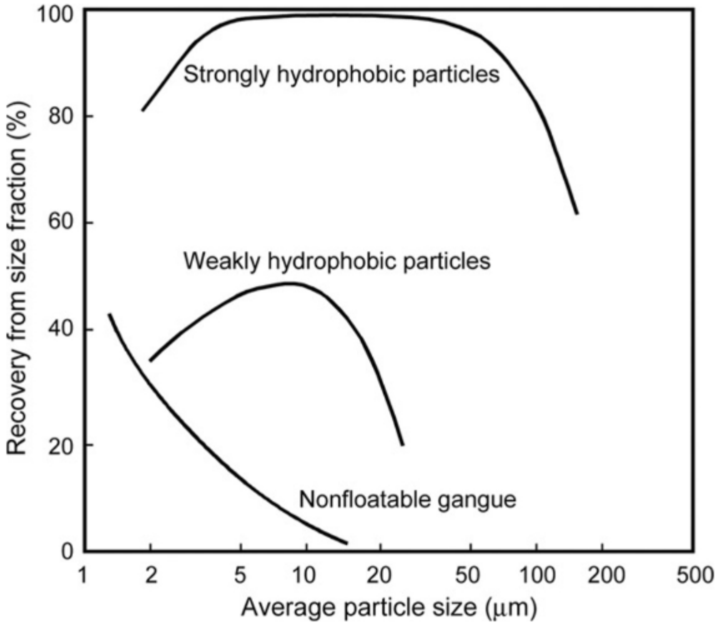


Figure 2.6: Typical dependence of the flotation recovery on the particle size and hydrophobicity (Nguyen et. al, 2004 cited by Nguyen 2014).

Vidyadhar & Singh state that, the primary mechanism of flotation entails the attachment of mineral particles to air bubbles in a way that causes the particles to float to the top of the ore pulp, where they may be collected. The steps in the procedure are as follows:

1. Grinding the ore to a fine enough size to separate the precious minerals from the gangue minerals and one another.
2. Creating conditions that encourage the desired minerals to attach to air bubbles.
3. Injecting an air current that is rising in the ore pulp.

4. Creating a frothy layer of minerals on top of the ore pulp.
5. Eliminating the mineral-rich foam.

Even while ore grinding isn't technically a part of flotation, it does have a significant impact on the procedure. The precious minerals should be thoroughly separated from the waste rock (gangue) and from one another in the grinding process for the best flotation results. However, this is not always economically viable, and even when total separation is achieved, further complicating variables could appear. As a result, significant gangue slimes may accumulate during the typical ball mill or rod mill grinding process, complicating the subsequent flotation procedures.

Latest study found by Parra Alvarez, 2022 state that a flotation machine works by mechanically agitating the ore pulp or by directly introducing air under pressure, or by doing both. The result is a rising stream of air bubbles. These actions could be thought of as the flotation process' mechanical adjuncts.

Froth flotation is a separation technique used in mineral processing that depends on variations in surface characteristics. differences in the degree of water affinity or hydrophobicity. A slurry is placed in a flotation cell, which has an impeller that stirs the mixture and releases bubbles from the bottom of the cell. Hydrophobic particles adhere to bubbles as they rise to the surface due to buoyancy, and when they do, a froth is formed. As long as the requisite separation is not reached, this froth is constantly removed. The hydrophilic particles, meanwhile, are not eliminated as an underflow product; they stay in the pulp or liquid phase.

2.4 Microflotation

Rutledge, 2016 in Fundamental Surface Chemistry and Froth Flotation Behavior state that flotation is a relatively complicated process with numerous variables. The operation parameters involve pH, collector concentration and collector category, frother, concentration and type, temperature, air circulation rate, and so forth. Microflotation is frequently used to dismantle the flotation process and understand the parameters that affect grade and recovery. Microflotation is commonly used as a preparatory step to bench scale flotation testing. In general, microflotation can be performed both on pure minerals and ores. Microflotation is used in the case of pure minerals to understand the interaction between the reagents and the mineral in question, whether gangue or valuable.

Pure mineral microflotation is remarkably helpful in understanding specific interactions among reagents and minerals, and it can be used to identify areas where flotation is most appropriate. For example, when pure mineral flotation is performed with the valuable and gangue minerals, an area (under constant conditions) is frequently found where the gangue is depressed and the valuable mineral floats. Microflotation is not only important for analyzing pure minerals, but it is also advantageous because it does not require large amounts of material, as is common in bench scale flotation.

2.5 Hallimond Tube

Initial floatability studies on freed mineral particles are frequently performed to evaluate a variety of acceptable collectors and regulators, as well as to identify the optimal pH for flotation. Dynamic circumstances exist in the Hallimond tube method. Inside the tube carrying the distilled water and the collector under test, the mineral particles are kept on a sintered glass support. Any hydrophobic mineral particles are raised by the bubbles, which burst at the water surface, enabling the particles to fall into the collecting tube. The weight collected in the tube can be connected to the floatability by treating a tiny, weighted sample of pure mineral or a combination of pure minerals (e.g., galena and quartz). The Hallimond tube has the benefit of avoiding the need for expensive assaying. However, because no frothers were employed in the test, it is unclear if the procedure accurately resembles commercial flotation (Wills *et al.*, 2006).

In industrial models, cost and temporal constraints restrict the flotation process from being streamed for an extended period of time. As a result, the optimum circuit is one with the least amount of time and the greatest amount of recuperation (Mohsen, 2009). The Hallimond tube is a laboratory flotation cell that is used to calculate recovery based on relative flotation rates. (Humeres et all, 1993).

Over the last four decades, several alternative methods of measuring floatability and quantifying flotation performance have been published in the literature. Release analysis, test-tube floatability, film flotation, froth less flotation, locked-cycle testing, contact angle measurements, Hallimond tube flotation, and the usage of innovative cell designs such as the dissolved air Hallimond tube are examples of these. (Farrokhrouz and Haghi, 2009).

NUTT et al., 1963 indicated that the Hallimond procedures can be used in the laboratory to test the flotation behaviour of tiny amounts of a mineral. The experiment is often designed so that the findings may be represented as a percentage of the initial mineral recovered by flotation after an arbitrary time interval.

Furthermore, according to Feasby, 1966, the flotation cell offers various benefits, including the use of a small quantity of sample (2-3 g), the ability to utilise a large number of conditions and reagent schedules in a short period of time, and the fact that neither the reagent concentration nor the volume of liquid fluctuates during the test. The flotation volume of the cell is around 100 ml, and bubble production is accomplished using pure nitrogen gas. The cell is equipped with a magnetic stirrer, a fritted glass bottom for gas admission, and a ground glass joint for ease of handling. The cell's well, consisting of a 29/42 Pyrex junction, is designed so that unfloated particles always rest on the fritted glass bottom. The cell may be clamped over a magnetic stirrer, and the particles are stirred using a polyethylene-coated magnet. The flotation factors include reagent concentration, conditioning time, flotation time, degree of aeration, and degree of agitation within the cell.

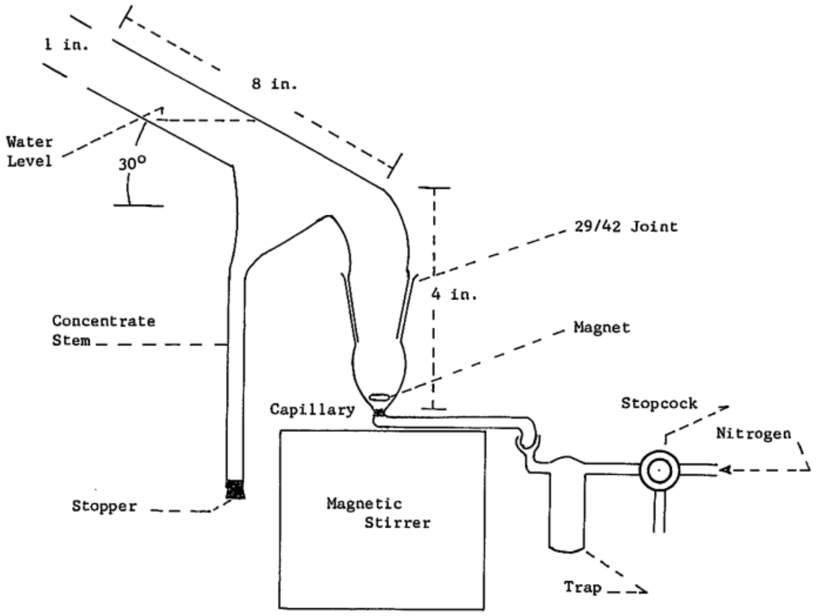


Figure 2.7: Hallimond tube (Feasby, 1966)

2.6 Reagents

Many chemicals from three main families are utilised in flotation, namely collectors, modifiers, and frothers, and their historical history matches that of flotation technology in general. Nagaraj and Ravishankar discovered three different phases of flotation reagent development after reviewing 100 years of flotation data. Flotation reagents are classed as collectors, frothers, or modifiers based on their function. All three types of reagents play vital functions and play important roles in intricate interactions. Thus, the flotation reagent triangle is made up of three types of reagents. (Figure 2.8).

Flotation reagents contain two crucial structural features: a functional group composed of donor atoms or ligands, and a substituent group composed of alkyl aryl hydrocarbon chains in the case of collectors and frothers, or hydrophilic in the case of modifiers (except for inorganic modifiers, which comprise mainly inorganic bases and metal ions). Appropriate structural adjustments are done to acquire the required characteristic or activity for a given separation (Figure 2.9 shows the types of changes and the properties affected) (Chander & Nagaraj, 2007).

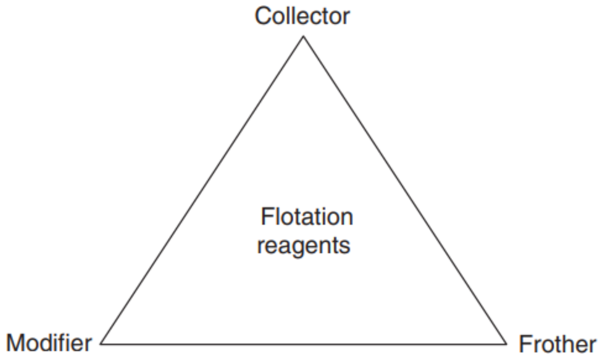


Figure 2.8: The reagent triangle (Chander & Nagaraj, 2007)

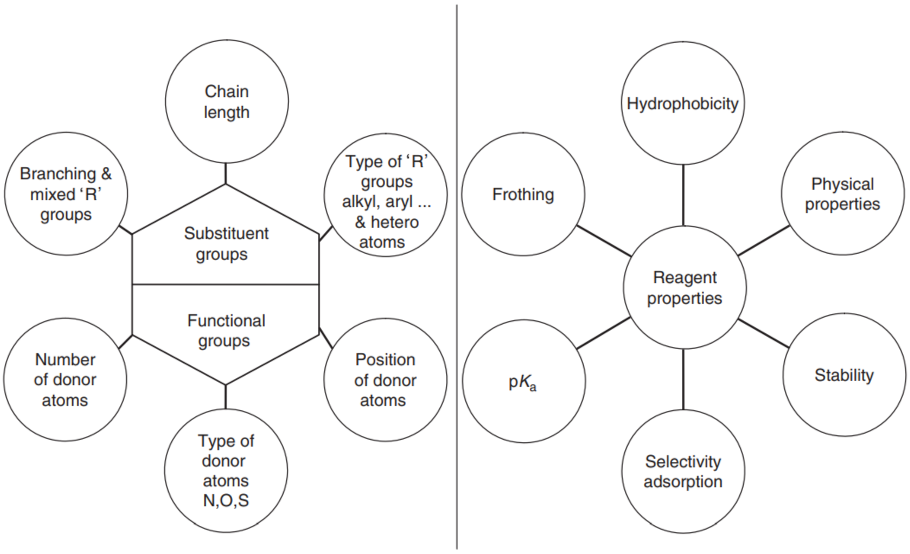


Figure 2.9: Structural features and the properties affected by changes in the structure (Chander & Nagaraj, 2007).

2.6.1 Collectors

Collectors are chemicals that selectively bind to the surfaces of particles. They create a monolayer on the particle surface, forming a thin layer of non-polar hydrophobic hydrocarbons. The collectors significantly enhance the contact angle, causing bubbles to stick to the surface. The suitable collector must be used for optimal froth flotation separation (Kawatra, 2021).

In addition, Kyaw Htin, 1950, express that the primary characteristic of the froth flotation process is the adhesion of a mineral particle previously wetted by water and an air bubble large enough to carry it to the surface. In practice, because the particles are so small in comparison to the bubbles, many of them become connected to each air bubble. A bubble that is highly mineralized may even sink to the bottom. It should be noted right away that this adhesion between the mineral and the bubble can only occur in the presence of a collector. Contact angle measurements with clean mineral surfaces in distilled water yielded zero contact angles, indicating that there was no sticking between the air bubble and the mineral surface.

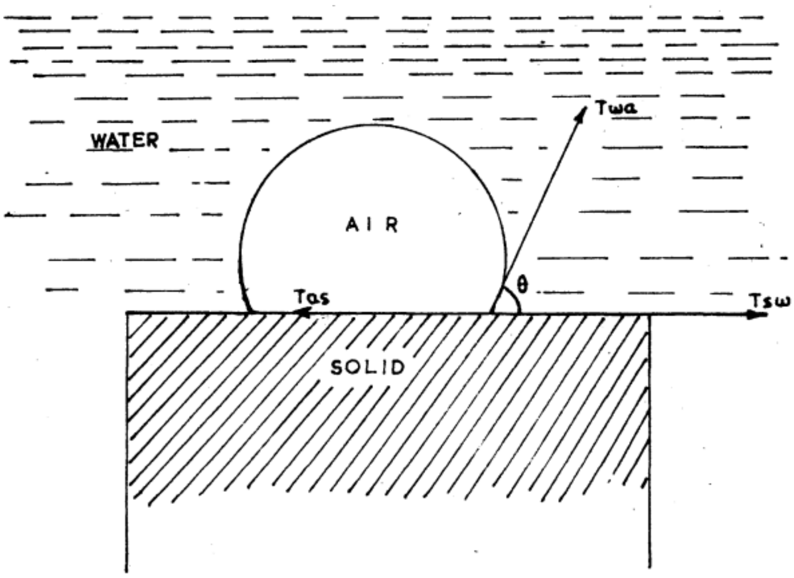


Figure 2.10: Equilibrium relationship for a bubble of air in contact with a mineral surface under water (Kyaw Htin, 1950).

Ionic (cationic and anionic) and non-ionic surfactants, sulfydryl, thio, thiol, nonthio, nonthiol, soluble, insoluble, greasy, hydrolyzable, ionizable, and so on are common classifications for collectors. In the case of sulphide minerals, where collector adsorption occurs primarily through chemisorption and surface chemical reactions involving specific functional groups (electrostatic effects are not very important), and there are many different collector families, the classifications mentioned above are insufficient. Collectors are invariably recognised and selected in the industry by their chemistry (e.g., dithiophosphates, thionocarbamate, and the associated chain lengths of hydrocarbon substituents), implying an immediate link between performance and a specific combination of functional group and substituents. In both research and practise, a categorization based on functional groups and substituents is more suitable and scientifically relevant (Chander and Nagaraj, 2007).

Most minerals must be given hydrophobicity in order to float. To do this, collector surfactants are introduced to the pulp and time is provided for adsorption during agitation during the conditioning stage. Collectors are organic compounds that, by adsorption of molecules or ions on the mineral surface, render selected minerals water-repellent, reducing the stability of the hydrated layer separating the mineral surface from the air bubble to the point where particle attachment to the bubble can occur on contact. Collector molecules can be ionising compounds that dissociate into ions in water, or non-ionising chemicals that render the mineral water-repellent by coating its surface with a thin layer (Wills *et al.*, 2006).

However, Wills et al., 2006 in Mineral Processing Technology, also stated that it is customary for a flotation system to include more than one collector. At the beginning of the circuit, a selective collector may be employed to float the highly hydrophobic minerals, followed by a more powerful but less selective collector to improve recovery of the slower floating minerals.

In general, the polar group is the component of the collector molecule that interacts with water and adsorbs on the mineral surface, whilst the hydrocarbon chain with water-repellent qualities extends to the solution and so offers hydrophobicity to the mineral surface (Figure 2.11). Figure 2.12 depicts a typical industrial flotation collector (Nguyen, 2013)**.**

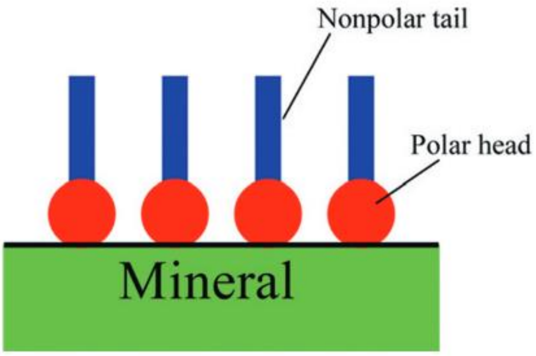


Figure 2.11: Adsorption of a polar collector at mineral-water interface (Nguyen, 2013)

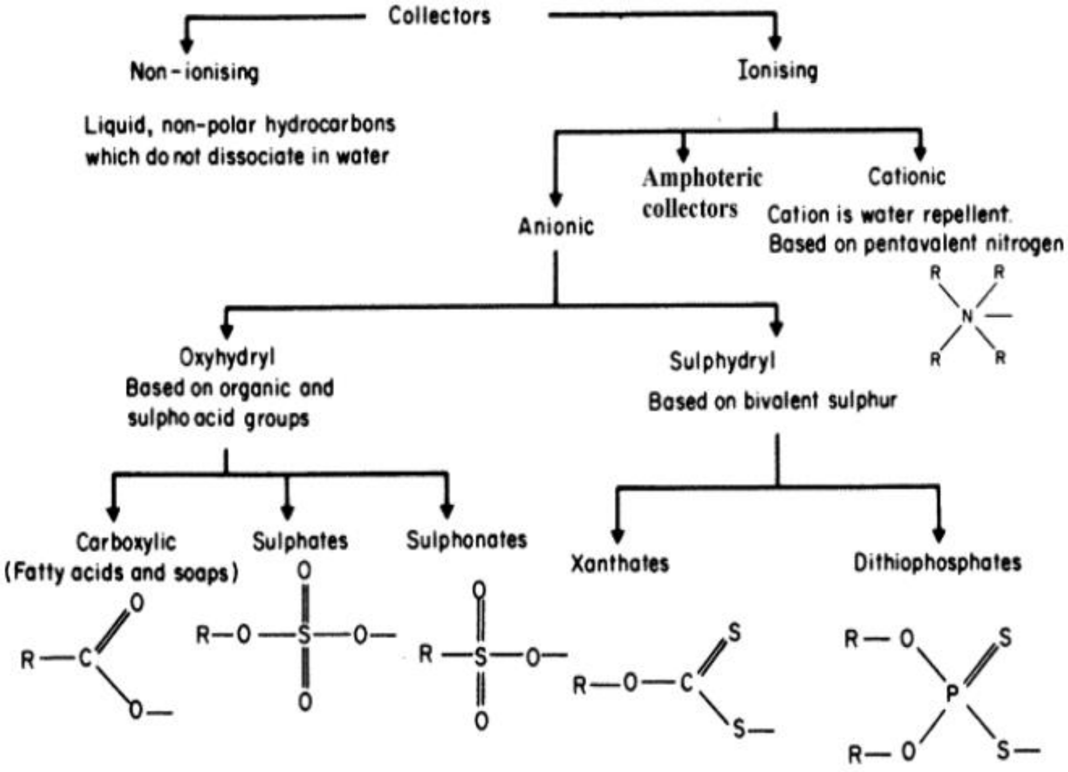


Figure 2.12: Classification of collectors (Glembotskii et al., 1972 cited by Wills et al., 2006)

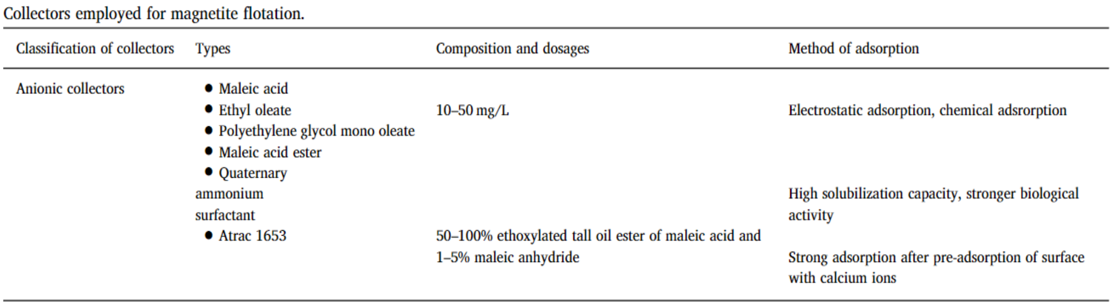
The primary role of a collector is to improve the possibility of bubble-mineral attachment by imparting adequate hydrophobicity to the mineral surface. A collector molecule performs this role by adsorbing on the mineral surface, as is well known. A collector is not always required; if a mineral is inherently hydrophobic, it can be floated without one (Chander & Nagaraj, 2007).

The iron oxide minerals that are isolated from the gangue mineral by direct flotation include hematite, goethite, and magnetite. Direct flotation of iron oxides utilising chosen anionic collectors such as petroleum sulphonates, fatty acids, and hydroxamates was the first step in iron ore flotation.

The improved adsorption of the surfactant was explored in the pH range 7.5 to 9.5 by pre-treatment of the magnetite surface with sodium silicate and calcium ions prior to surfactant adsorption, with maximum adsorption obtained at pH 8.5. This finding is consistent with the findings of Morgan et al., who described the creation of an acid-soap complex [(RCOO)-2H] for oleate adsorption on magnetite. (Pattanaik & Venugopal, 2018).

Potapova, 2009 state that positively charged ions were discovered to boost the anionic collector's adsorption on magnetite above its point of zero charge because they lowered the effective negative charge of the surface, hence lessening the electrostatic repulsion between the collector and the surface.

Direct flotation of iron oxides utilising anionic collectors such as petroleum sulphonate, fatty acids, and hydroxamates began the history of iron ore flotation. Fatty acids (a distilled tall oil comprising roughly 91 percent oleic and linoleic acids, 6 percent rosin acid, and 3 percent unsaponifiable) are employed as an iron oxide collector, at a dose of 0.45-0.67 kg/t (Ma, 2012).



Collectors employed for magnetite flotation.

Classification of collectors	Types	Composition and dosages	Method of adsorption
Anionic collectors	● Maleic acid ● Ethyl oleate ● Polyethylene glycol mono oleate ● Maleic acid ester	10–50 mg/L	Electrostatic adsorption, chemical adsrorption
	● Quaternary ammonium surfactant		High solubilization capacity, stronger biological activity
	● Atrac 1653	50–100% ethoxylated tall oil ester of maleic acid and 1–5% maleic anhydride	Strong adsorption after pre-adsorption of surface with calcium ions

Figure 2.13: Collectors employed for magnetite flotation (Pattanaik & Venugopal, 2018)

2.6.1(a) Anionic collector

Anionic collector is the most often employed collectors in mineral flotation and are categorized into two categories based on the polar group structure. The polar groups of oxyhydryl collectors are organic and sulpho-acid anions, and the cation plays no role in the reagent-mineral interaction, as with all anionic collectors (Wills *et al.*, 2006).

Typically, oxyhydryl collectors are organic acids or soaps. The carboxylates are known as fatty acids and occur naturally in vegetable oils and animal fats from which they are extracted by distillation and crystallisation. The salts of oleic acid, such as sodium oleate and linoleic acid, are commonly used. As with all ionic collectors, the longer the hydrocarbon chain length, the more powerful is the water-repulsion produced, but solubility decreases. Soaps (the salts of fatty acids), however, are soluble even if the chain length is long. The carboxylates are strong collectors but have relatively low selectivity. They are used for the flotation of minerals of calcium, barium, strontium, and magnesium, the carbonates of non- ferrous metals, and the soluble salts