3 EFFECT OF A MAGNETIC FIELD ON THE MOVEMENT AND FLOTATION RESPONSE OF A FERRIMAGNETIC PARTICLE

3.1 Introduction

During flotation, hydrophobic particles attach to air bubbles and float. Applying an oscillating magnetic field to a flotation column, where magnetically susceptible particles are present, will not only affect the movement of the magnetically susceptible particles, but will also affect the flotation response of these particles.

The properties of the applied magnetic field, e.g. frequency, field strength and orientation of the magnetic field relative to the particle, determine the behaviour of the magnetic particles in the magnetic field. Under specific conditions, the magnetic field can be used to oscillate the magnetic susceptible particles. Depending on the orientation of the magnetic field, some of the particles attached to the air bubble may even lose contact with the air bubble.

The behaviour of a magnetically susceptible particle in an oscillating magnetic field and its effect on flotation are investigated in this chapter. Various combinations of magnetic field strengths and frequencies were used in flotation and visual experiments. To prevent the magnetic field from retaining the magnetic particles in the magnetic field, experiments were done at various frequencies to determine the minimum magnetic field strength required to retain any magnetic susceptible particles in the field. Flotation tests, with varying magnetic field strengths and frequencies, were done in a Hallimond tube to establish the effect of the magnetic field on the flotation of sulphide particles. Orientation of the magnetic field, either parallel or perpendicular to a rising bubble, was investigated using a Hallimond tube.

A laboratory flotation column was used to investigate the effect of positioning the magnetic field in both the particle collection zone and in the middle of the column. In the collection zone at the bottom of the column, the hydrophobic particles attach themselves to the air bubbles. These particles are then transported to the top of the column by the rising bubbles. By varying the position of the electro-magnet on the column flotation cell, the effect of a magnetic field on the collection and rising stages of bubbles was investigated.

The strength of the bond between the bubble and the particle is of importance in flotation. Increasing the strength of the bond between the particle and the bubble, by adding increasing amounts of collector to the system, should prevent the particle and bubble from losing contact even when oscillated by an oscillating magnetic field. Flotation tests in a Hallimond tube with sulphide minerals and varying amounts of collector was done in the presence of an oscillating magnetic field to examine the effect of collector on the flotation performance of the sulphide minerals.

Finally, the effect of residence time of a magnetically susceptible particle in an oscillating magnetic field on flotation was investigated. The residence time in a magnetic field will determine the number of oscillations induced on a pyrrhotite particle, which will also influence the flotation of pyrrhotite in a magnetic field.

3.2 Experimental set-up and procedures

3.2.1 Mineral sample preparation

A nickel sulphide sample was ground in a pulverising mill. The -150μm fraction was removed from the milled product by dry sieving. Oversized material, +150μm, was recycled to the mill. This procedure was repeated until the whole sample passed through a 150μm screen. The -63μm fraction was also removed by dry sieving. The -150 +63µm samples were stored in airtight containers to minimise surface oxidation.

Optical techniques were used to determine the mineralogical composition of the samples as shown in table 3-1. The sample was also assayed for nickel, copper and iron by the Nkomati Mine laboratory. Iron (28%) was the major component with lesser amounts of nickel (0.9%) and copper (0.5%).

Table 3-1: Mineralogical composition of the sulphide sample.

Pyrrhotite	85%
Chalcopyrite	2%
Pentlandite	4%
Pyrite	1%
Magnetite	5%
Silicate minerals	3%

3.2.2 Reagent preparation procedure

Potassium amyl xanthate (PAX) obtained from Senmin was used as a collector for the sulphides. To ensure the quality of the PAX, it was purified by dissolving the crystals in acetone and removing the undissolved crystals and impurities from solution by filtration. The PAX was recrystalised by evaporating the solvent under vacuum and the crystals were stored in an airtight container to prevent oxidation.

3.2.3 Conditioning procedure

Just prior to the flotation experiments, oxidation products were removed from the surface of the particles, by conditioning in a hydrochloric acid solution. One gram of sample was mixed with 50ml of a 10-volume percent hydrochloric acid solution before exposing it to an ultrasonic bath for 2 minutes. After this treatment, the sample was rinsed 3 times with 100ml of distilled water.

One gram of the sample was conditioned in 100ml of 10 mg/l PAX solution. A perspex stirrer and impeller were used to agitate the mixture to prevent the particles from settling out and to improve the mass transfer of the collector. During the conditioning of the sample in the PAX solution, the temperature was kept constant by immersing the conditioning beaker in a water bath at 20°C. The pH was controlled at 7.4 by the addition of a potassium dihydrogen ortho phosphate/ di-sodium hydrogen ortho phosphate pH buffer to the conditioning solution. The conditioning time was kept constant at 10 minutes for all the experiments.

3.2.4 Experimental set-up for the generation of magnetic fields

Electromagnets were coupled to an alternating current source to produce magnetic fields. Magnetic fields, oscillating either parallel or perpendicular to the rising bubbles, were generated with frequencies between 1 and 160Hz and a magnetic field strength of up to 1600 Gauss.

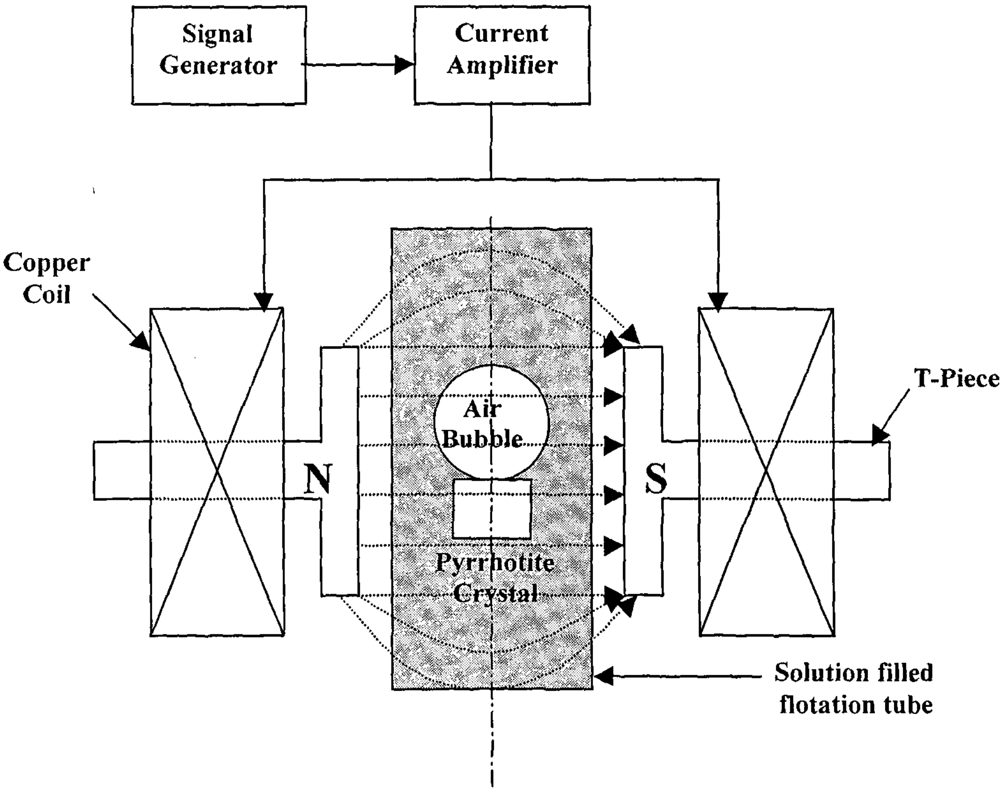

Figure 3-1: Experimental set-up used to produce a linear magnetic field perpendicular to a rising bubble.

The copper coils were driven by a sinusoidal voltage signal, produced by a Krohn-Hite 1000A function generator and amplified by a PA 500 power amplifier, as shown in figure 3-1. The function generator allowed for the variation of current and frequency of the input signal to the electromagnets. The strength of the magnetic field was measured using a Hall probe.

A magnetic field, perpendicular to the rising bubble, was produced by winding copper coils around two mild steel T-pieces. The uniformity of the magnetic field produced between the two T-pieces is shown in figure 3-2 At the edges of the plates, the magnetic field lines were concentrated and the magnetic field strength increased. This is also reflected in the magnetic field profile in figure 3-2, which shows the magnetic field strength along the length of the plates and at two different radial positions (centerline and at radius 20mm from the centerline). The plates were 45mm long and 20mm wide.

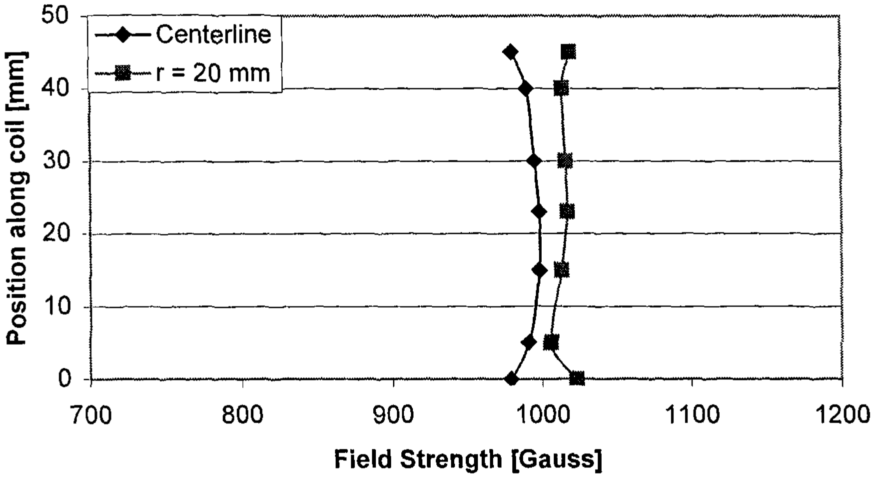

Figure 3-2: Magnetic field strength profile along the centerline and at a radius of 20mm from the centerline of a magnetic field perpendicular to a rising bubble using the experimental set-up as described in figure 3-1.

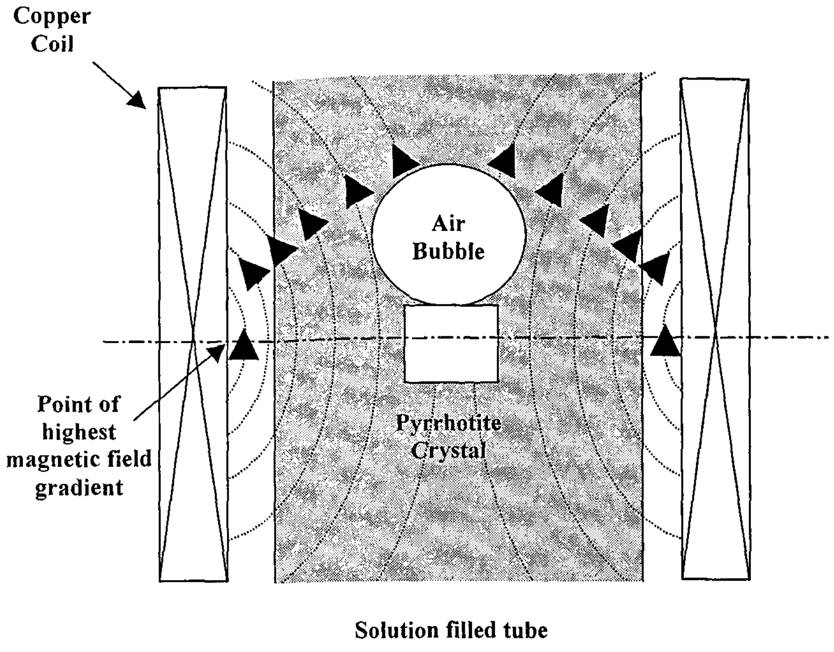

Figure 3-3: Experimental set-up, using copper coils, to generate a magnetic field parallel to the movement of rising bubbles.

The magnetic field parallel to gravity was generated by using copper coils, which were 45mm and 100mm long respectively, with an internal diameter of 55mm and which fitted around the flotation column. The shape of the magnetic field lines and the field gradient in the coil are schematically represented in figure 3-3. Figure 3-4 and figure 3-5 show the magnetic field profile along the length of the magnetic coil at the centerline and at a radius of 20mm from the centerline. For both the 45mm and 100mm long coils, the magnetic field strength was the highest in the middle of the coil. The magnetic field in the middle of the coil was higher at a radius of 20mm than the magnetic field at the centerline for both magnetic coils.

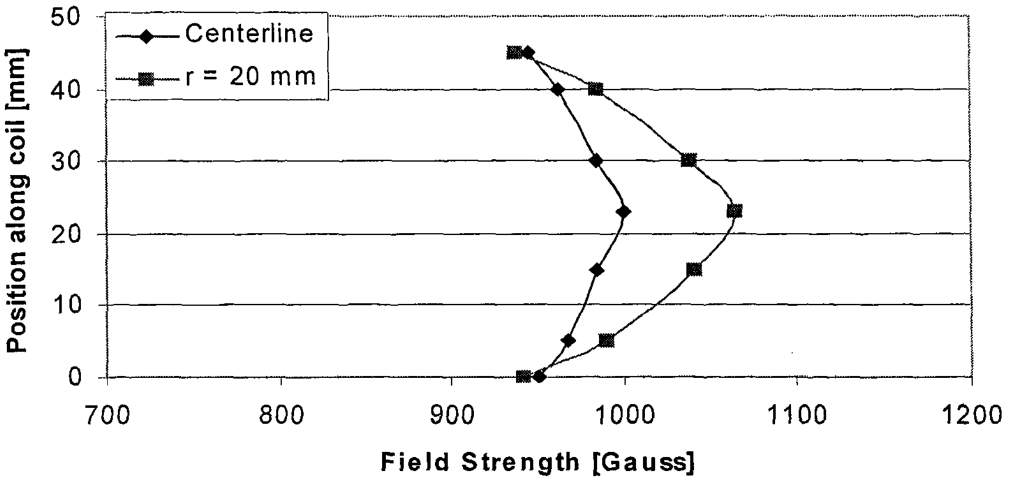

Figure 3-4: Magnetic field strength profile along the centerline and at a radius of 20mm from the centerline of the copper coil 45mm long using the experimental set-up as described in figure 3-3.

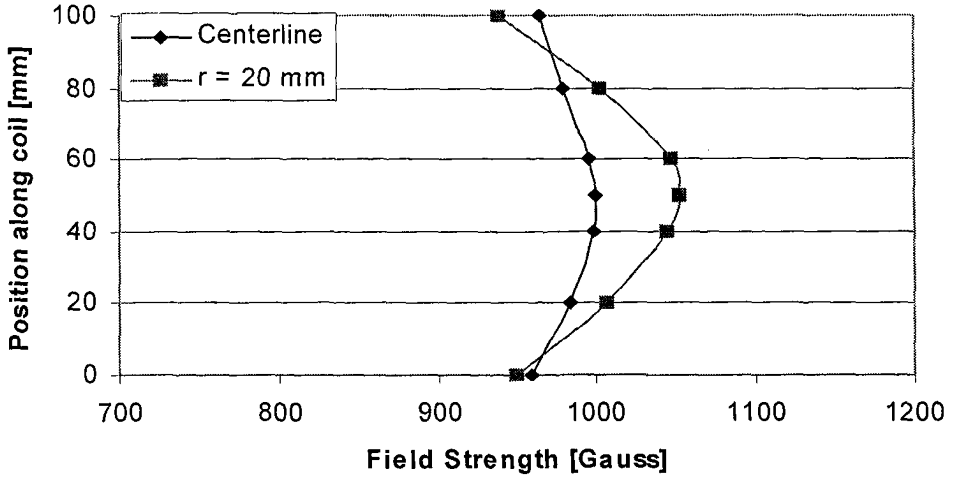

Figure 3-5: Magnetic field strength profiles along the centerline and at a radius of 20mm from the centerline of the copper coil 100mm long using the experimental set-up as described in figure 3-3.

3.2.5 Visual observations of particle movement in an applied magnetic field.

3.2.5.1 Experimental set-up

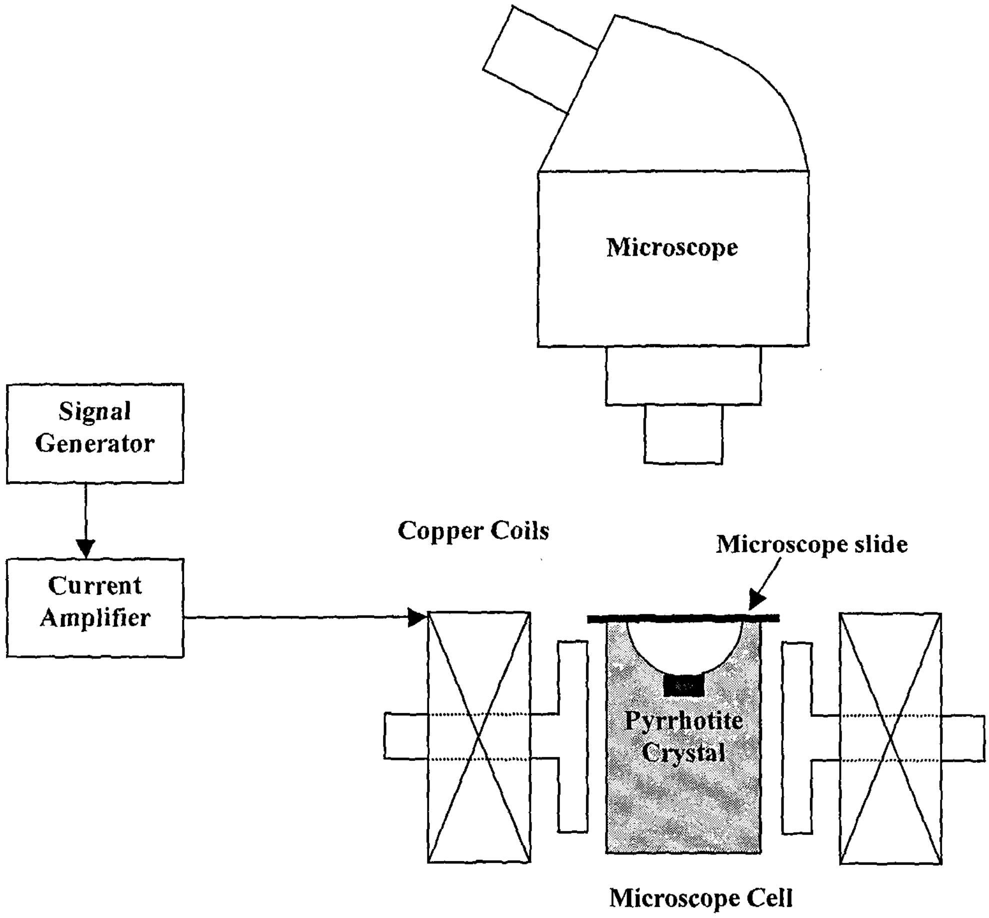

Figure 3-6: Experimental set-up to visually examine the oscillation of a magnetically susceptible crystal in a magnetic field.

The experimental set-up, shown in figure 3-6, was used to visually examine the relationship between frequency, magnetic field strength and oscillation of a magnetically susceptible particle.

3.2.5.2 Experimental procedure

One gram of crushed sample (-150μm +63μm) was conditioned in 100ml of a 10mg/l Potassium Amyl Xanthate (PAX) solution for 10 minutes. A measure of the solution and approximately 0.1g of sample was transferred to the microscope cell shown in figure 3-6. A microscope slide was used to cover the cell. A bubble was injected into the bottom of the cell through a silicon sealed opening, using a hypodermic needle and syringe. The bubble rose through the sample bed and collected the hydrophobic sulphide particles. The loaded bubble then rose to the top of the cell where it adhered to the bottom of the microscope slide. A Nikon SMZ-10 binocular microscope was used to visually observe the behavior of the magnetically susceptible particles in a magnetic field.

3.2.6 Set-up to investigate retention of magnetically susceptible particles in a magnetic field

3.2.6.1 Experimental set-up

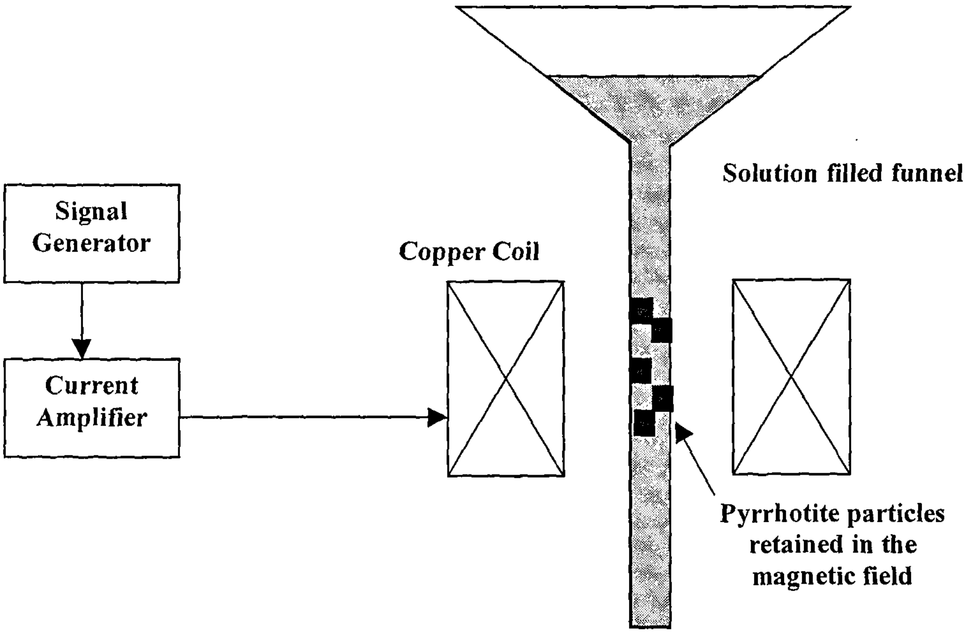

Figure 3-7. Experimental set-up for the examination of the retention of magnetically susceptible particles in a magnetic field.

A funnel was placed in the 45mm long copper coil as shown in figure 3-7 and a current was supplied to the coil by the frequency generator and the current amplifier as described before.

3.2.6.2 Experimental procedure

The frequency of the magnetic field was set and the magnetic field was increased to maximum. The funnel was sealed at the bottom and filled with water, after which approximately 0.2 grams of milled sulphide sample (-150 +63μm) was added to the top of the funnel. The sample moved through the magnetic field where the magnetic fraction of the sample was retained in the magnetic field. The magnetic field strength was reduced to a point where none of the particles were retained in the magnetic field. At this point the funnel was removed from the magnetic field and the magnetic flux was measured using a Hall probe. Both the magnetic flux and frequency were recorded. The experiments were repeated at several different frequencies.

3.2.7 Hallimond tube flotation procedure

3.2.7.1 Experimental set-up

A glass Hallimond tube as shown in figure 3-8 was used for flotation tests. A magnetic field was applied to the flotation tube by fitting an electromagnet, as described earlier, to the flotation tube. Both the magnetic field strength and frequency were controlled using the set-up described before. Pressurised air was injected into the bottom of the tube and the flowrate was controlled using a rotameter.

3.2.7.2 Experimental procedure

After conditioning, the mineral sample and the xanthate solution were transferred into the Hallimond tube shown in figure 3-8. The mineral sample settled at the bottom of the tube. Air was bubbled from the bottom of the tube at a rate of 0,037l/min for 1 minute. The flotation concentrate was collected in a small tube at the side of the Hallimond tube.

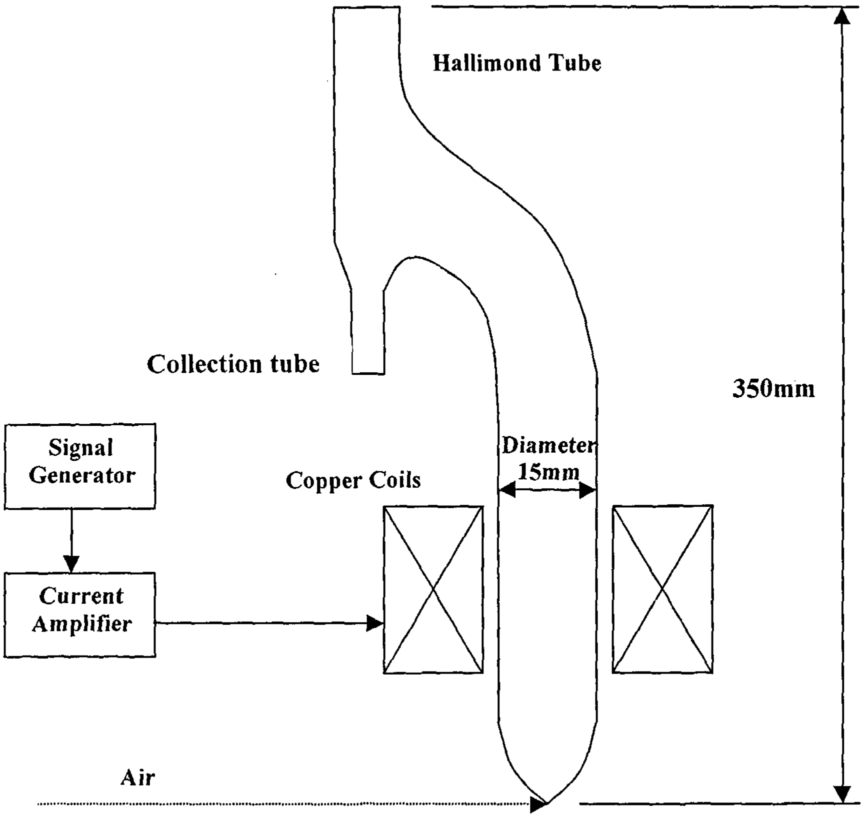

Figure 3-8. Experimental Hallimond flotation set-up with an electro magnet fitted to the tube to apply an oscillating magnetic field to the tube during flotation experiments.

After the test was completed, the flotation concentrate sample in the collection tube and the flotation tail sample that was left in the bottom of the tube were drained into separate beakers before they were filtered, dried and weighed. The flotation recovery was calculated by dividing the mass of the concentrate by the total mass of the sample and expressed as a percentage recovery.

3.2.7.3 Effect of magnetic field strength and frequency on flotation

A magnetic field was applied to the Hallimond tube by fitting a 100mm long copper coil with a 55mm diameter over the bottom of the flotation tube as shown in figure 3-8. A range of frequencies and magnetic field strengths were applied to the tube during the flotation experiments, with a summary of conditions given in table 3-2.

3.2.7.6 Effect of residence time in a magnetic field on flotation of the sulphide sample

To vary the residence time in the magnetic field, two coils with lengths of 45mm and 100mm were alternatively fitted to a Hallimond tube. The residence time in the magnetic field was estimated by measuring the time it took a single bubble to rise through the length of the Hallimond tube. The ratio between the length of the copper coil to the total length of the tube was multiplied by the total rising time to give the retention time in the magnetic field. Conditions for this experiment are given in table 3-2.

3.2.8 Position of magnetic field

3.2.8.1 Experimental set-up

A flotation column shown in figure 3-9 was used to investigate the flotation behaviour of pyrrhotite with magnetic fields applied to different positions of the column. The plastic column was 350mm long with a diameter of 25mm. Air was injected from the bottom of the column through a glass frit to produce air bubbles. The bubbles collected hydrophobic particles which rose to the top of the column where a stable froth formed. The froth overflowed from the top of the column and was collected in a beaker. During the experiments the solution level was kept constant by using a steady head tank.

The 100mm long copper coil with an inside diameter of 55mm, was placed over the column. The magnetic field was controlled by coupling the copper coil to the power and signal generators as described earlier. The magnetic field was respectively applied to the bottom and middle of the column to test the effect of the magnetic field position on the flotation response of pyrrhotite.

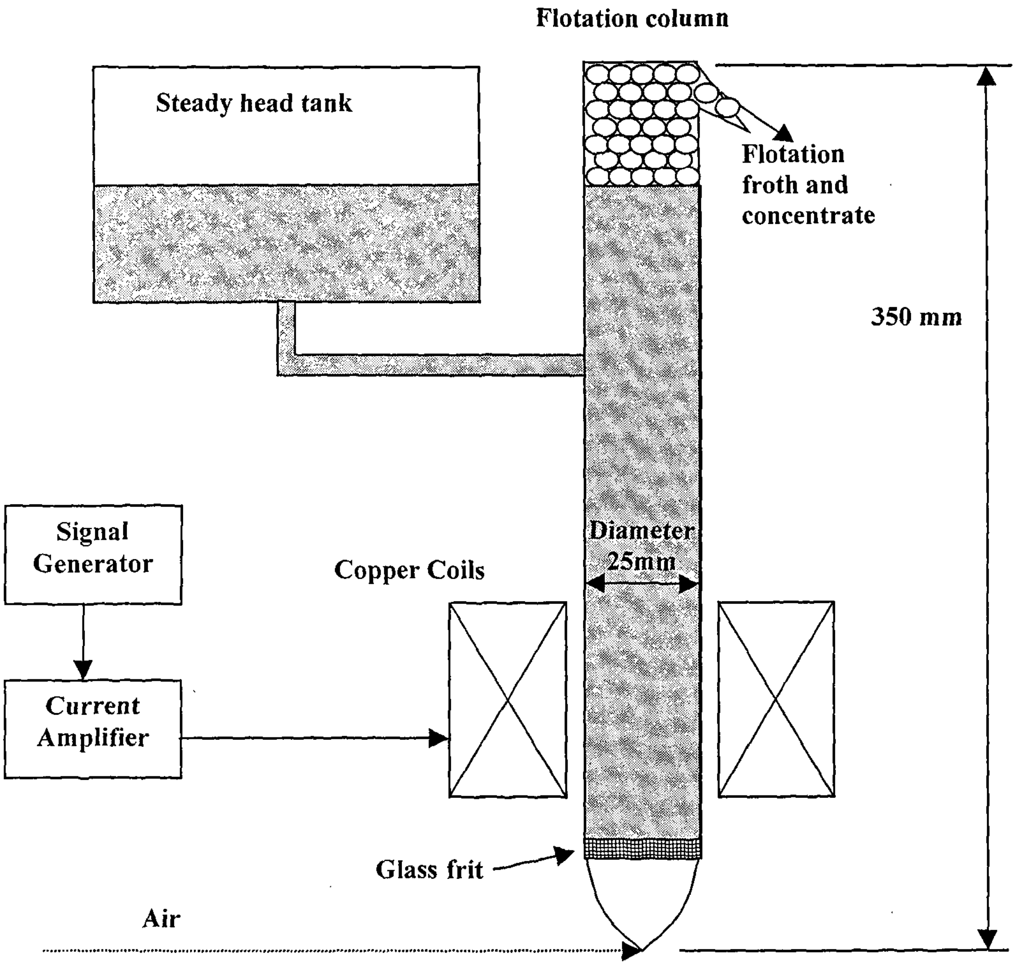

Figure 3-9. Experimental set-up for column flotation tests with an oscillating magnetic field applied to the bottom of the flotation column.

3.2.8.2 Experimental procedure

The sample preparation of the sulphide sample was the same as that described for the Hallimond flotation tests. Two grams of sample was conditioned in a 10 mg/l PAX solution while the temperature was kept constant at 20°C by immersing a 300ml Pyrex beaker in a water bath. The pH was controlled at 7.4 by the addition of a potassium dihydrogen ortho phosphate/ di-sodium hydrogen ortho phosphate pH buffer to the conditioning solution. A stable froth was obtained by adding 20mg/l of Aerofroth 65 frother (Cyanamid) to the conditioning solution.

Table 3-2: Experimental conditions to examine the effect of various parameters on flotation recovery of a sulphide sample (-150µm +63µm) *in a Hallimond tube* .

Experiment		**Magnetic field strength and frequency**	**Magnetic field orientation**	**Collector concentration**	**Residence time in a magnetic field**
Flotation Time	sec	60	60	60	60
Conditioning Time	min	10	10	10	10
Conditioning Temperature	°C	20	20	20	20
pH		7.4	7.4	7.4	7.4
Xanthate Concentration	mg/l	10	10	Variable	8
Magnetic Field Frequency	Hz	Variable	50	50	50
Magnetic Field Strength	Gauss	Variable	Variable	800	800
Magnetic Field Type		Coil	Variable	Coil	Coil

3.2.7.4 Effect of magnetic field orientation on flotation.

A magnetic field perpendicular and parallel to the rising bubble, as described in figure 3-1 and figure 3-3, were respectively applied to the Hallimond flotation tube. A frequency of 50Hz with various magnetic flux densities was used for the experiments. The length of the magnetic coil and the magnetic T-pieces was 45mm.

3.2.7.5 Effect of collector concentration on flotation of pyrrhotite

The collector concentration during conditioning was varied from 0 to 50mg/l PAX and the magnetic field was kept constant at 100Hz and 800 Gauss with the rest of the sample preparation, conditioning and flotation procedures as described before. Table 3-2 shows the conditions for this experiment.

After conditioning for 10 minutes, the mineral sample and the solution was transferred to the flotation column shown in figure 3-9. The column and glass frit were used to fluidise the mineral sample, which formed a static bed in the Hallimond tube. The water level in the column was kept constant during the flotation test, by using a steady head. Air was introduced at the bottom of the column for 30 seconds at a rate of 0.074l/minute through a glass frit.

The froth was collected in a glass vessel at the top of the column. The concentrate and the residue were dried at a temperature of 110°C.

A magnetic field generated, as described earlier, of 800 Gauss at a frequency of 50Hz was respectively applied to the bottom and middle of the flotation tube. Table 3-3 summarises the experimental conditions for this experiment.

Table 3-3: Experimental conditions to examine the effect of magnetic field position during pyrrhotite flotation.

Flotation Device	Flotation Column	
Flotation Time	30	sec
Conditioning Time	10	min
Conditioning Temperature	20	°C
pH	7.4	
Airflow rate	0.074	l/min
Xanthate Concentration	5×10^{-5}	M
Aerofroth 615	20	mg/l
Magnetic Field Frequency	50	Hz
Magnetic Field Strength	800	Gauss
Magnetic Field Type	Coil	

3.3 Results and discussion

3.3.1 Rotation of a magnetically susceptible particle in a magnetic field

The behavior of a ferromagnetic material in a magnetic field can be best described by a simplified hysteresis loop shown in figure 3-10.

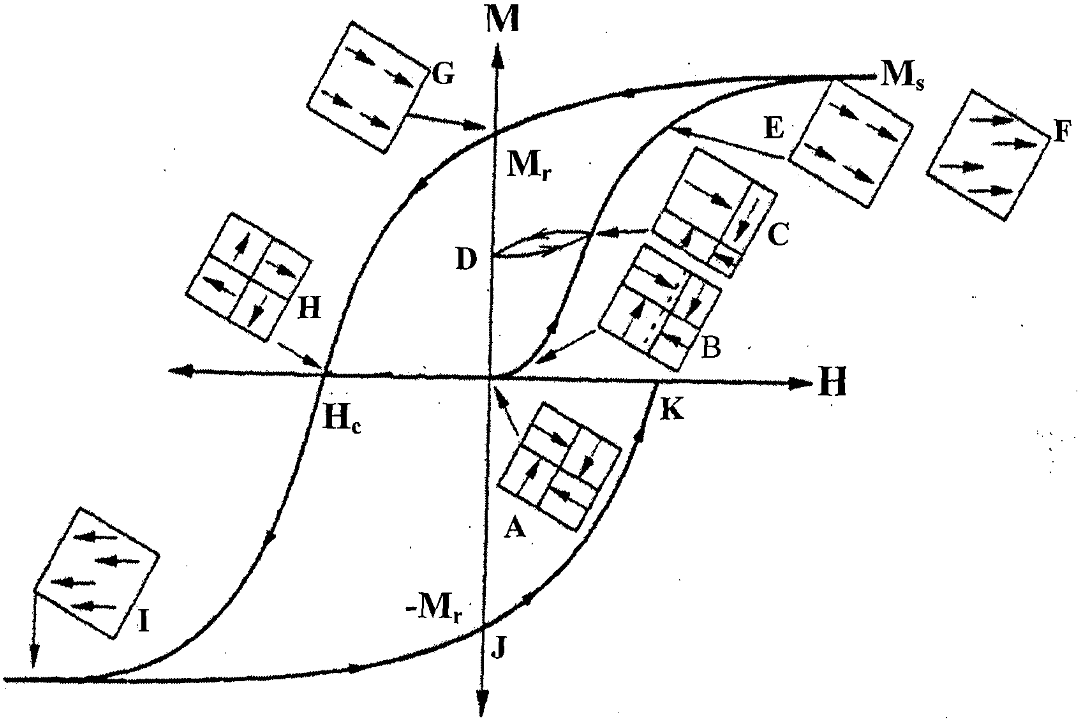

Figure 3-10: Magnetic response curve for a ferromagnetic material subjected to a magnetic field of varying intensity. The behavior of the magnetic domains are indicated by arrows (After Bate and Kryder, 1993)

- With no magnetic field applied to the sample depicted by position A, the internal magnetic domains cancel each other out and the net magnetisation of the sample is zero.
- With a small positive increase in the magnetic field to position B, the domains with orientation closest to the applied field will increase, while the domains opposing the magnetic field will decrease. The domain walls will be displaced

as the domains grow and the displacement of the domain walls is reversible at position B.

- A further increase in the field strength to position C, will result in the growth of the dominant domains. The movement of the domain walls is irreversible at position C.
- If the field is removed, the magnetisation (M) would return to a value at position D.
- Near the knee of the magnetisation curve, position E, all the domain walls will be removed by the applied magnetic field, but the orientation of the induced magnetisation is not parallel to the applied magnetic field.
- At position F, the orientation of the magnetisation is parallel to the external field and no magnetic dipoles exist that can be orientated in the direction of the applied magnetic field and the sample is magnetically saturated (M_s).
- Upon removing the applied magnetic field, the magnetisation of the sample will return to position G. This retained magnetisation is called the remnant magnetisation (M_r).
- To return the sample to its original magnetisation state, a negative external field (H_C) must be applied to the sample at position H. The domains reappear and although the net magnetisation is again zero the domains may be magnetised differently from that of the initial sample.
- By increasing the field strength to position I the process described above will repeat itself.

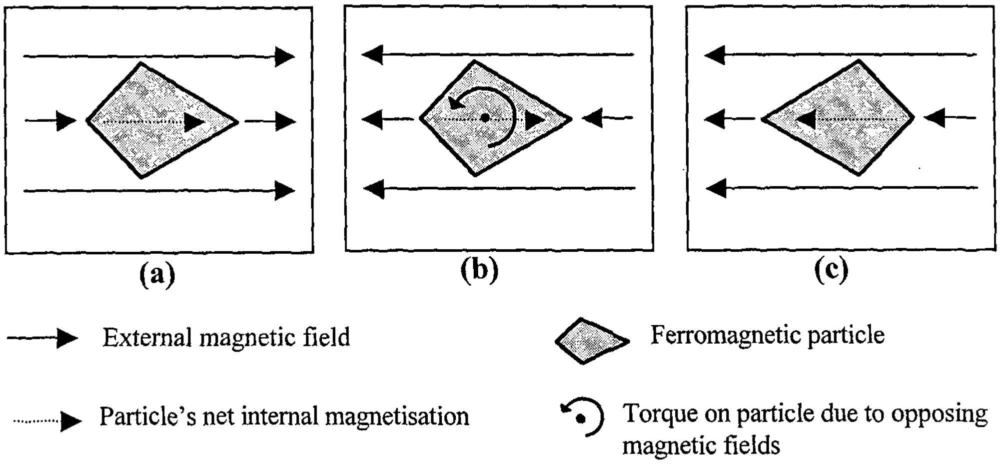

Figure 3-11 :Schematical representation of the behaviour of a free rotating ferromagnetic particle in an oscillating magnetic field. a) Internal and external magnetic fields are aligned. b) Particle's remnant magnetic field opposing the external magnetic field. c) Rotated particle with internal and external magnetic fields aligned with each other.

A ferromagnetic particle, placed in an oscillating magnetic field and allowed to rotate without any physical constraints, is schematically presented in figure 3-11 a-c. The particle is magnetised in the direction of the external field as shown in figure 3-11(a). When the external magnetic field is removed, there would still be remnant magnetisation present in the particle. The effect of reversing the polarity of the external magnetic field is shown in figure 3-11(b). The remnant magnetisation of the particle would now oppose the external magnetic field. A torque is thus produced on the particle to align the particle's internal magnetic field with the external magnetic field. The torque causes the particle to rotate to a position where the internal and external magnetic fields are aligned as shown in figure 3-11(c). By continuously reversing the magnetic field, the process described above will cause the particle to rotate.

Ferrimagnetic materials, like monoclinic pyrrhotite, exhibit the same behavior as ferromagnetic materials, except for the anti-ferromagnetic fraction of the material which aligns itself non-parallel to the external magnetic field.

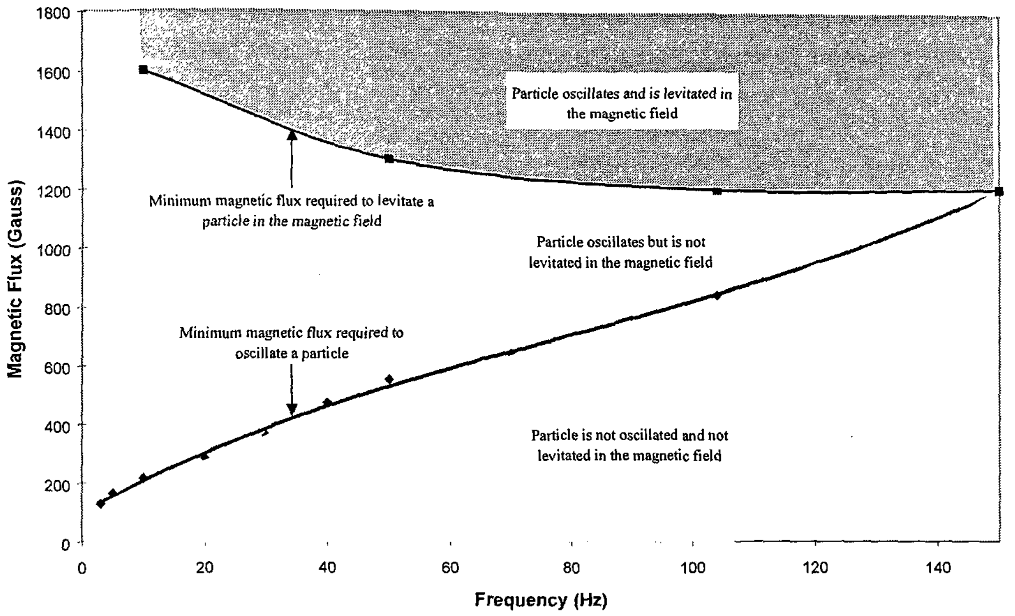

Figure 3-12. Relationship between minimum magnetic flux density and magnetic field frequency required to oscillation and retention of a 75μm magnetically susceptible pyrrhotite particle.

With the visual set-up, as described earlier, the relationship between rotation of a magnetically susceptible particle and the external magnetic field was examined. Figure 3-12 shows the relationship between the required magnetic flux density required to rotate a 75μm magnetically susceptible particle as a function of the magnetic field's frequency. It was found that the magnetic field strength necessary to oscillate the magnetically susceptible particle, increased with an increase in frequency of the magnetic field.

As the frequency of the magnetic field increased, the inertia and the drag forces on the magnetically susceptible particle played an increasingly important role to limit the oscillation of the particle. An increased magnetic field must therefore be applied at the higher frequencies to oscillate the particle as shown in figure 3-12.

With low frequencies and high magnetic field strengths, the particle will be able to rotate through 180° to align itself with the external magnetic field. At higher frequencies, the particle will be magnetised in the direction of the magnetic field before it is able to complete the 180° rotation. Under these circumstances it was observed, using the visual set-up described earlier, that the particle still oscillates but the angle through which it oscillated was less than 180°.

3.3.2 Retention of magnetically susceptible particle in a magnetic field

The data in figure 3-12 also shows the dependence of frequency and the magnetic flux density on the retention of magnetically susceptible particles in the magnetic field produced by a coil. The retention line in figure 3-12 indicates the minimum magnetic field strength required to retain any of the sample in the magnetic field at a specific frequency. In all the flotation experiments, the field strength was kept below the retention line to prevent accumulation of magnetically susceptible particles in the magnetic field.

A minimum magnetic field is necessary to retain the particles in the coil. But since the magnetic field strength changed in a sinusoidal fashion, there were periods when the magnetic field was not strong enough to retain the particles in the magnetic field. During these periods the particles moved downwards under the influence of gravity. If a particle moved too far down, the magnetic field was not able to retract the magnetically susceptible particle back into the magnetic field when the magnetic field again increased in strength. The distance covered by the particle during the period where the magnetic field was not strong enough to retain the particle in the magnetic field, was dependent on the frequency of the magnetic field. With frequencies lower than 40Hz, the particle gravitated downwards and the magnetic field necessary to retain the particles, had to be increased as shown in figure 3-12.

3.3.3 Effect of a magnetic field on flotation

The Hallimond tube flotation results for the pyrrhotite sample are shown in figure 3-13 a to d. From the data, it is clear that both the frequency and magnetic flux had an effect on the flotation recovery. The minimum flux needed to oscillate a 75μm magnetically susceptible particle is shown by the broken lines.

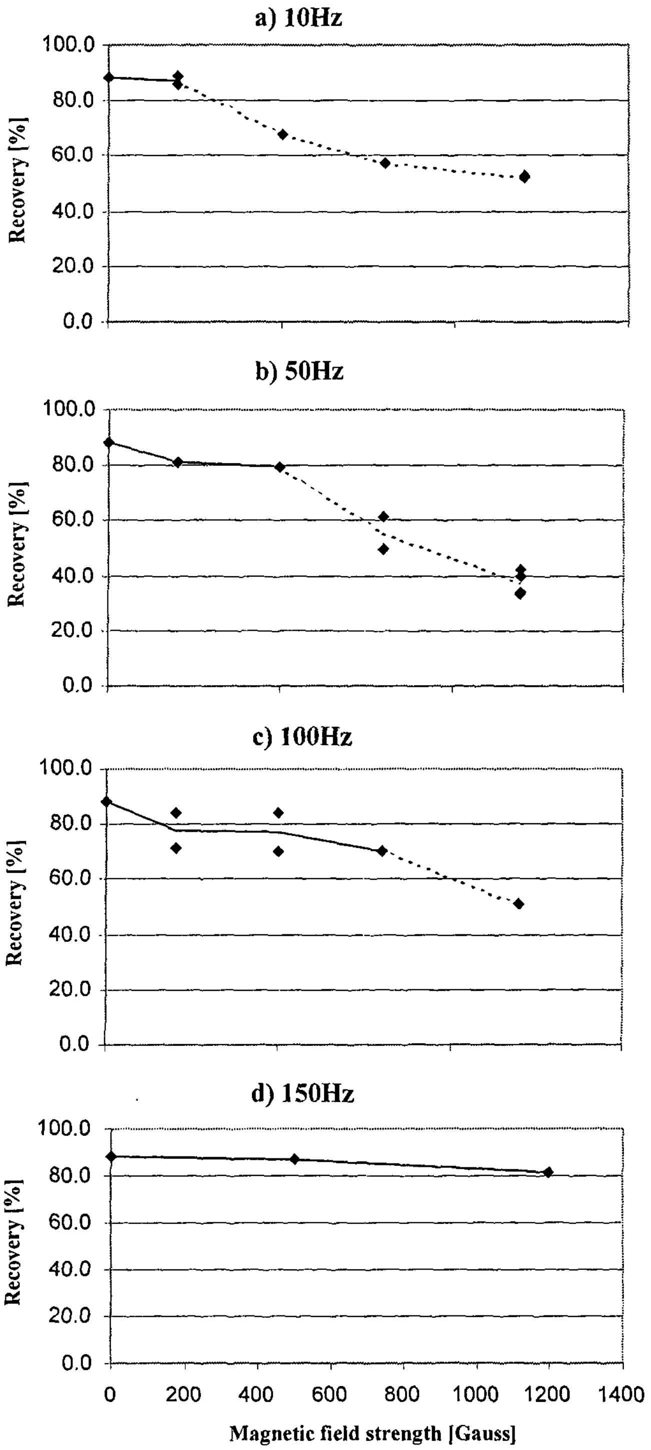

Figure 3-13. Effect of magnetic field strength and oscillation frequency on flotation recovery of the pyrrhotite sample at a) 10Hz, b) 50Hz, c) 100Hz, d) 150Hz.

In general, it was found that flotation recoveries were not reduced when the particles were not oscillated. For example, with a magnetic oscillating frequency of 10Hz, the flotation recovery stayed relatively constant until the magnetically susceptible particles started to oscillate. The flotation recovery decreased further with increasing magnetic flux density. The increased magnetic flux density increased the torque induced on the magnetically susceptible particle, causing the particle to oscillate more vigorously and to lose contact with the air bubble.

The flotation response of the sample at frequencies of 10, 50, and 100Hz all showed the same trend of decreasing flotation recovery with an increase in magnetic flux, once the particles started to oscillate. The magnetic flux density where a decrease in flotation was observed, increased with frequency and correlated well with the magnetic flux densities necessary to oscillate a 75μm particle, as shown in figure 3-12. The flotation recovery of magnetically susceptible particles at 150Hz stayed constant with magnetic flux, since the magnetically susceptible particles were not oscillated.

3.3.4 Effect of magnetic field orientation on flotation

It was noted, from the visual observations described earlier, that the orientation of the magnetic field relative to the magnetically susceptible particle influenced the motional behavior of the particle.

An oscillating magnetic field, perpendicular to the rising bubble shown in figure 3-14(a), magnetised the particle in the direction of the applied magnetic field. When the polarity of the external magnetic field was reversed, the polarity of the particle's remnant magnetisation opposed the external magnetic field as shown in figure 3-14(b). The opposing magnetic fields generated a torque on the particle around an axis perpendicular to the applied magnetic field. With this direction of rotation, the contact between the bubble and the particle was not challenged and the particle rotated without losing contact with the air bubble. Finally, the particle was rotated to align the internal and external magnetic fields as shown in figure 3-14(c).

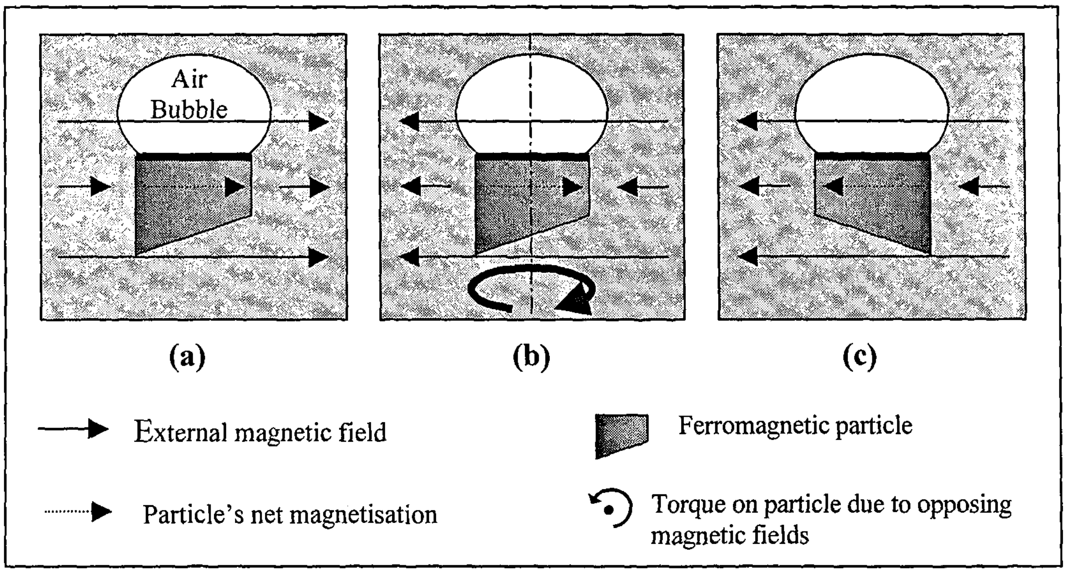

Figure 3-14: Schematical representation of the behaviour of a ferromagnetic particle attached to an air bubble in an oscillating magnetic field perpendicular to the rising bubble. a) Internal magnetic field and external field aligned. b) Particle's remnant magnetic field opposing the external magnetic field. c) Rotated particle with internal and external magnetic fields aligned with each other.

Figure 3-15 describes the behaviour of a ferromagnetic particle, attached to an air bubble, in an oscillating magnetic field parallel to the direction in which the bubble rose. Figure 3-15(a) shows how the external magnetic field magnetises the ferromagnetic particle in the direction of the applied magnetic field. In figure 3-15(b) the direction of the torque on the particle due to the opposing internal and external magnetic fields is shown. It is clear that the contact between the air bubble and particle resists the torque that is applied to the particle. If the particle is not homogeneously hydrophobic, which is typically the case, bubble / particle contact must be broken before the particle can rotate as shown in figure 3-15(c). The implication of this loss of contact between the bubble and the particle during flotation is that the flotation recovery of the particles will decrease.

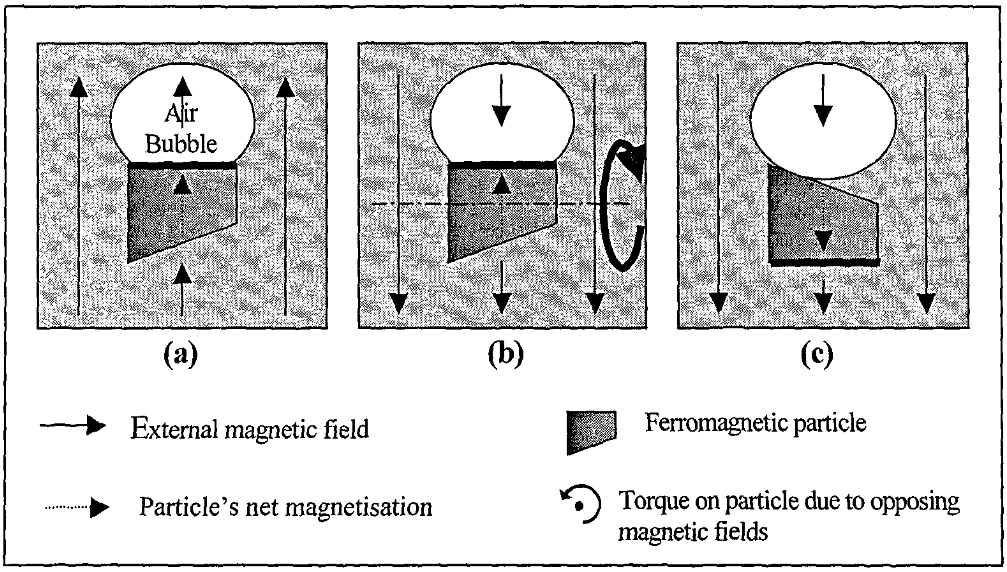

Figure 3-15: Schematical representation of the behaviour of a ferromagnetic particle attached to an air bubble in an oscillating magnetic field parallel to the rising bubble. a) Internal magnetic field and external field aligned. b) Particle's remnant magnetic field opposing the external magnetic field. c) Rotated particle with internal and external magnetic fields aligned with each other.

For magnetic fields alternating parallel to the rising bubble, shown in figure 3-3, it was visually observed that the magnetically susceptible particles attached to the bubble, moved to the side of the bubble, where they oscillated around an axis perpendicular to the applied magnetic field. For a coil, the position with the highest field gradient is shown in figure 3-3. A magnetically susceptible particle, attached to an air bubble, is attracted to the point with the highest field gradient. In this case, the magnetically susceptible particle will move to the side of the air bubble, where it will rotate around an axis perpendicular to the magnetic field lines. However, during flotation the particle will be washed to the bottom of the rising air bubble by the solution.

It was observed using the visual set-up, that the magnetically susceptible particles that did not move to the side of the bubble rotated around an axis perpendicular to the applied field and lost contact with the bubble.

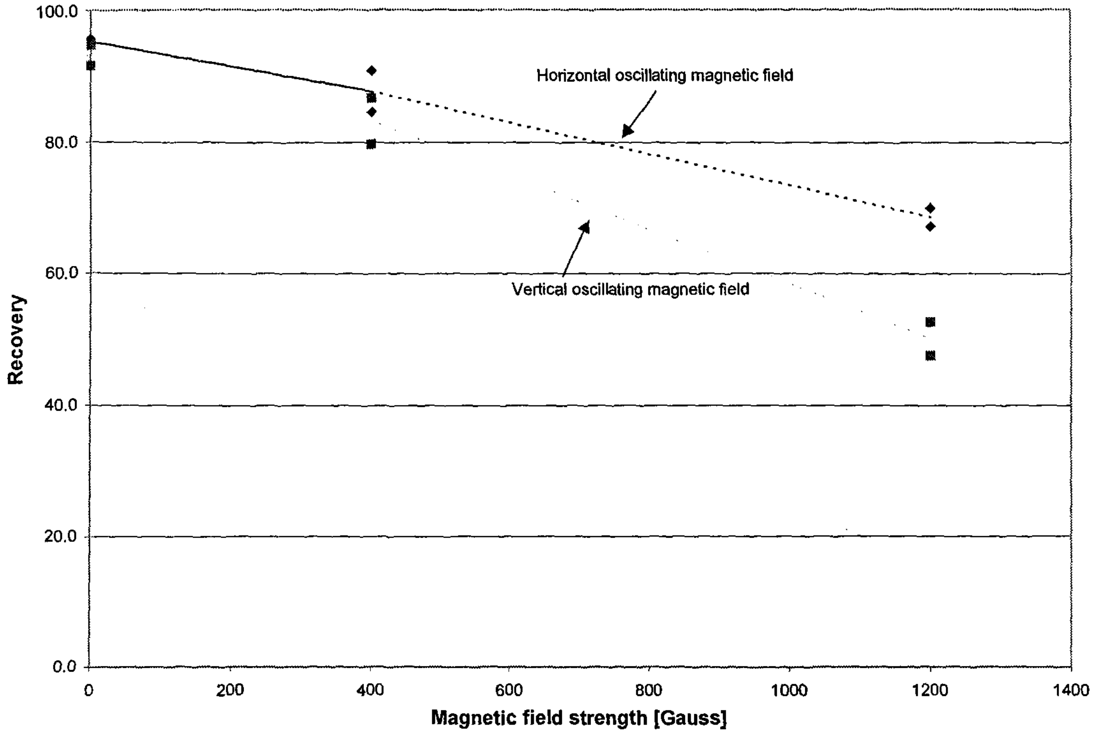

Figure 3-16. Influence of magnetic field orientation on the flotation in a Hallimond tube. Broken lines indicate magnetic flux densities where the magnetically susceptible particle oscillates.

Figure 3-16 shows the effect of the magnetic field orientation on the flotation with increasing magnetic field strength. Note that when magnetic oscillations are induced, shown as broken lines in figure 3-16, the flotation recovery starts to decrease. As would be expected, the magnetic field parallel to the rising bubble has a more pronounced effect on flotation recovery than a magnetic field perpendicular to gravity.

3.3.5 Effect of magnetic field position on flotation

By varying the position of the magnetic field, the effect of a magnetic field on the various stages of flotation was investigated. At the bottom of the flotation column, the air bubbles collected the hydrophobic sulphide. By applying a magnetic field at the bottom of the flotation column, the magnetically susceptible particles were oscillated, increasing the probability that a hydrophobic surface will attach to the rising air bubble. The already attached particles will also oscillate and may lose contact with the air bubble.

By moving the magnetic field to the middle of the flotation column, the collection of the pyrrhotite particles are less likely to be influenced, as only the particles which are already attached, will be subjected to the magnetic field.

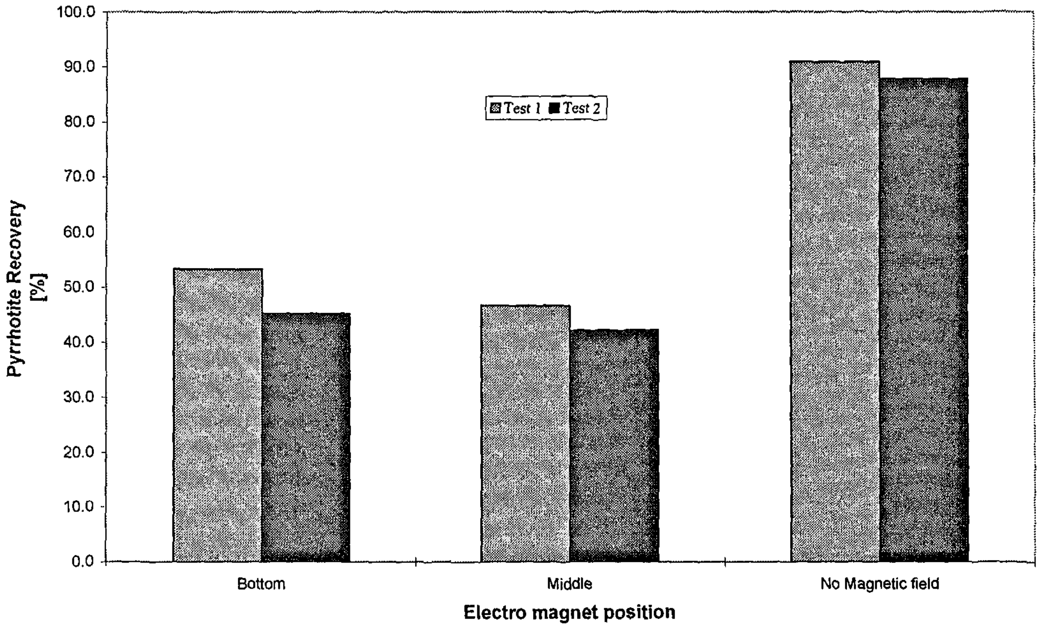

Figure 3-17. Effect of positioning of the magnetic field (50Hz, 800 Gauss) on the flotation of pyrrhotite.

Figure 3-17 shows the flotation recovery of pyrrhotite with a magnetic field positioned at the bottom and middle of the flotation column respectively; also shown is the flotation recovery of pyrrhotite when no magnetic field was present.

It is clear that the magnetic field depressed the flotation of pyrrhotite due to the oscillations induced on the particles by the external oscillating magnetic field. The flotation recovery was not sensitive to the position of the magnetic field, i.e. at either the bottom or the middle of the flotation column. It would thus indicate that the flotation recovery was not enhanced by the oscillation of the magnetically susceptible particles during the collection stage, but rather that the detachment of the particles, as a result of the oscillation, was more prominent when a magnetic field was applied to the flotation column.

3.3.6 Effect of collector concentration on flotation in a magnetic field

It is obvious that flotation will only occur if the pyrrhotite establishes and maintains contact with the bubble. The presence of a collector will favour bonding between the particle and the bubble, while movement such as that caused by an oscillating magnetic field will tend to challenge this bond. It can be expected that the coverage will increase with increasing collector concentrations, making the bond between pyrrhotite and the bubble less vulnerable.

Figure 3-18 shows that the flotation recovery increased with an increase of collector concentration both in the presence and absence of a magnetic field. The difference between the flotation recovery with and without a magnetic field decreased with increasing collector concentrations. At a concentration of 50mg/l PAX no significant difference in the flotation recovery was notable. The sample showed natural floatability, which explains the 50% pyrrhotite recovery when no collector was present.

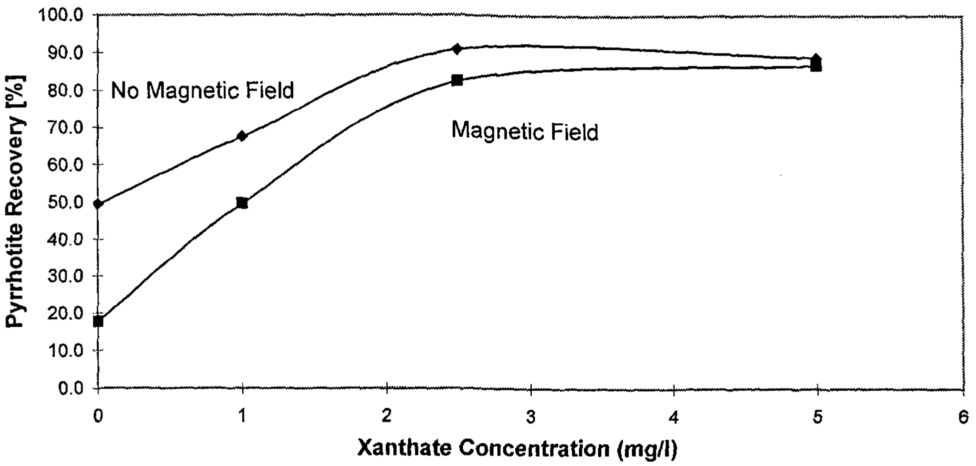

Figure 3-18. Influence of collector concentration on the flotation of pyrrhotite in an oscillating magnetic field (50 Hz, 800 Gauss).

With an increase in collector concentration, the hydrophobicity of the sulphides increased and the flotation recovery increased. The decrease in flotation recovery, when a magnetic field was applied to the flotation process, can be explained in terms of the hydrophobicity of the particles and the magnetically induced oscillations of the particles. With no collector, the hydrophobic fraction of the particle's surface is at a minimum. When a magnetically induced torque is applied to the particle attached to the bottom of a bubble, the hydrophobic bonding force may not be able to counter the magnetically induced torque and the particle would lose contact with the air bubble. From figure 3-18, it can be seen that the maximum effect of a magnetic field on flotation is attained with no collector present.

As the collector concentration increases, the hydrophobic area on the particle's surface and the strength of the hydrophobic bond would probably increase. It would be more difficult for the magnetically induced torque on the pyrrhotite particles to detach the particle from the bubble. The increased contact area between the particle and air bubble or the stronger bond would offer more resistance to the applied torque. The result is that the flotation will be less adversely affected.

3.3.7 Effect of residence time in a magnetic field on flotation.

Increasing the residence time of the magnetically susceptible particles attached to an air bubble in a magnetic field, will enhance the effect of a magnetic field on flotation. The probability that the particle will lose contact with the air bubble increases with the number of oscillations induced on the pyrrhotite particle by the external magnetic field. The number of oscillations is a function of the residence time and frequency of the magnetic field.

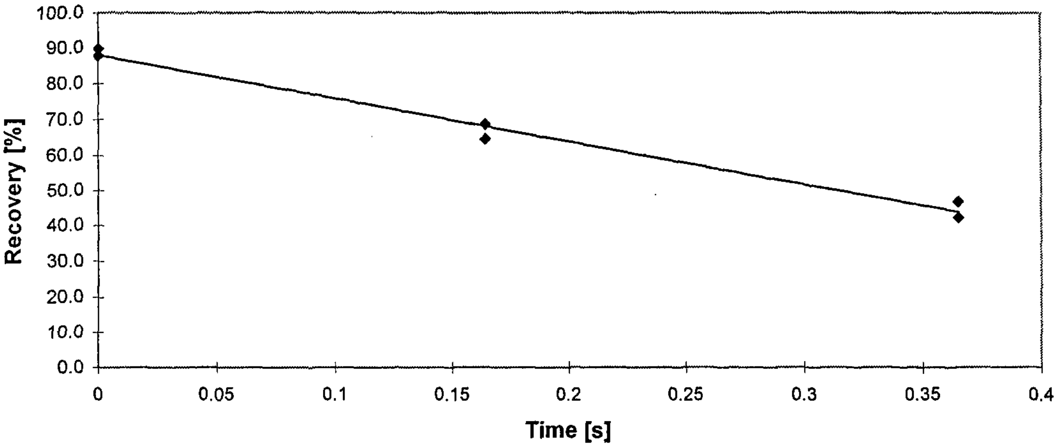

Figure 3-19. Influence of residence time in an oscillating magnetic field (50Hz, 800 Gauss) on the flotation of pyrrhotite

From figure 3-19, it is clear that the increased residence time in the magnetic field had a negative influence on the flotation recovery. At a frequency of 50Hz and a residence time of 0.02 seconds, 1 oscillation was induced on a pyrrhotite particle; similarly 2.25 oscillations were induced on the magnetically susceptible particle if the residence time is increased to 0.045 seconds. Figure 3-19 shows that the flotation recovery decreased with an increase in the number of oscillations induced on the pyrrhotite particle. The increase in the number of oscillations increased the probability that a magnetically susceptible particle will lose contact with the air bubble and thus decreased the probability of flotation.

3.4 Conclusions

The interaction between a magnetic field and a particle is dependent on the magnetic properties of the particle and on the properties of the magnetic field. The magnetic properties of minerals typically present in pulps differ, which implies different responses to a magnetic field. Typical examples are pyrrhotite (ferrimagnetic), pyrite (paramagnetic), and quartz (diamagnetic).

Visual experiments showed that magnetically susceptible particles attached to an air bubble were mechanically oscillated, under certain conditions, when an external magnetic field was applied to a flotation device. The oscillation of these particles was dependent on the frequency and the magnetic flux of the external magnetic field. The magnetic flux required to rotate the magnetically susceptible particles increased with the frequency. Also, the magnetic field strength necessary to retain a magnetically susceptible particle in a magnetic field decreased as the frequency was increased.

The flotation tests showed that there was a definite interaction between the magnetic field and magnetically susceptible particles during the flotation process. The magnetically susceptible particles may oscillate depending on the frequency and magnetic flux density of the magnetic field. Where oscillations were induced on the magnetically susceptible particles, the flotation recovery decreased. This decrease could be ascribed to the relative movement between the particles and the air bubble, which resulted in the loss of contact.

The orientation of the magnetic field determined the direction of oscillation of the magnetically susceptible particles. A field perpendicular to gravity caused the magnetically susceptible particles attached to an air bubble to oscillate freely, whilst a magnetic field parallel to gravity caused the particles to lose contact with the air bubble.

The flotation of magnetically susceptible minerals is depressed by a magnetic field, but there is no significant difference in the depressing effect of the magnetic field when the position of the magnetic field along the length of the tube was changed. Rather, the detachment of the oscillating pyrrhotite particles seems to dominate the flotation behavior of the pyrrhotite in a magnetic field.

Sulphide mineral flotation tests with increased concentrations of PAX collector, in the presence of a magnetic field, showed that the effect of the magnetic field diminished as the collector concentration increased. With an increase in collector concentration, the hydrophobicity of the particles increased with the result that the strength of the bond between the bubble and the particle also increased. The induced oscillations were thus not able to break the bond between the bubble and the pyrrhotite particles and flotation recovery was not significantly affected by a magnetic field at higher collector concentrations.

The retention time in the magnetic field and the frequency of the oscillation of the magnetic field, determine the number of oscillations induced on a magnetically susceptible particle. With an increase in the number of oscillations on the particles, the probability of the particles losing contact with the bubbles increased and the flotation recovery decreased.