

CONCLUSIONS & RECOMMENDATIONS**Chapter
5****5.1 Conclusions****5.2 Hypotheses revisited****5.3 Recommendations****5.1 Conclusions**

The following main conclusions, drawn from the results obtained from this investigation, can be made:

- The extraction of the metals nickel, copper and cobalt from a sulphide concentrate, in an oxidative pressure-acid medium, is definitely viable with recoveries of higher than 90% in a leaching period of 150 minutes.
- The oxidising of the minerals pyrrhotite (Fe_{1-x}S), pentlandite $(\text{Ni,Fe})_9\text{S}_8$ and chalcopyrite (CuFeS_2), at a oxygen partial pressure of 10 bar and a temperature of 110°C in the presence of sulphuric acid, can be described by means of the process reactions described in section 2.6.5.
- The iron hydrolysis and precipitation that occur during the leaching of the above mentioned minerals can be described by the reactions discussed in section 2.6.5.
- The present research suggests that the leaching kinetics of pentlandite, pyrrhotite and chalcopyrite can be explained in terms of a mixed chemical/diffusion controlled model, with the following, more universal, model preferred for fitting data of such nature:

$$x = 1 - e^{-kt} \quad \dots\dots\dots(20)$$

where, x = leached fraction, k = reaction constant (1/min) and t = time (min)

- Mechanical activation by means of ultra fine milling offers significant advantages for the processing and selective leaching of complex sulphide concentrates.
- The rate of leaching increases with increasing temperature and pressure, with optimum conditions found to be at a temperature of 110°C and a 10 bar oxygen pressure. The extraction of the copper from chalcopyrite is much more dependent on the temperature than the extraction of the nickel and cobalt from the pentlandite.
- A stirring rate of 600 r/min and more, appeared to be adequate to disperse oxygen sufficiently fast to ensure that the reaction rate was not limited by gas-liquid mass transfer.
- The rate of leaching decreases with an increasing pulp density for the extraction of nickel and cobalt, however the leaching rate for the extraction of copper increased initially with an increase in pulp density and decreased at a solid content of above 15%.
- Sulphuric acid concentrations of above 30 kg/ton did not have a remarkable influence on the metal recovery.
- From literature, the leaching of chalcopyrite concentrate is slow and ineffective, results from the present investigation indicated exceptional copper recoveries from chalcopyrite with the presence of other minerals. Results suggest that the presence of iron-containing minerals like pyrrhotite and pentlandite seems to enhance the extraction of copper from chalcopyrite due to a possible galvanic coupling of the different minerals present.
- The ferric iron in the leach solution act as an oxidant and improves the leaching kinetics prior to the hydrolysis and regeneration of the iron.

- The addition of nitrogen species such as HNO_3 resulted in no further improvement on the leach kinetics of the specific minerals studied.
- The use of silver catalysts for the enhancement of copper recoveries is not recommended in the presence of pentlandite and pyrrhotite concentrates.
- The passivation of mineral surfaces by a progressively thickening layer of copper rich polysulphide was not observed in this research. Factors responsible for depassivating chalcopyrite surfaces in this research is still under discussion. Results from this research suggest that below 121°C this layer is relatively porous and does not greatly hinder the diffusion of the solvent into the ore.
- The values for the apparent activation energies of nickel, copper and cobalt were found to be $20.6 (\pm 4.4) \text{ kJ/mol K}$, $33.6 (\pm 4.2) \text{ kJ/mol K}$ and $17.4 (\pm 3.5) \text{ kJ/mol K}$, respectively.

5.2 Hypotheses revisited

In view of the conclusions reached, the hypotheses put forward in chapter 1 can now be evaluated.

- The main oxidising products from the leaching process of sulphides were elemental sulphur and metal sulphates when leaching took place under a temperature of 120°C in an acidic medium.
- Hypotheses 2, relating to the advantage of ultra fine grinding as a pre-treatment method has been shown to be true.
- It was found that the agitation rate had a significant influence on the metal recovery for a diffusion-controlled reaction, proving hypotheses 3.

- Hypotheses 4 to 7 involving the effect of temperature, sulphuric acid concentration, pulp density and oxygen partial pressure on the leaching efficiency have been demonstrated to be substantially true.
- Metal recoveries, from chalcopyrite and pentlandite, of better than 90% were achieved after a leaching period of 150 minutes at a temperature of 110°C. The first part of hypotheses 8, concerning the ineffective leaching of copper from chalcopyrite, is therefore not valid.

5.3 Recommendations

Future investigations that might be considered are:

- The calculation of the actual oxygen consumption of the leaching reaction by means of mass flow meters.
- The influence on leaching kinetics with simultaneous grinding and leaching of complex sulphide concentrates.
- Intensive investigation on possible reaction products hindering the selective leaching of valuable metals from sulphide concentrates.
- Investigation on the physical transformation of specific mineral particles during the leaching process in order to develop accurate leaching models.