3.4. ANALYTICAL METHODS

Nickel, phosphorus, magnesium, and sulphate concentration levels in solution were determined by emission spectroscopy. In some cases total iron concentration level in solution was also determined by emission spectroscopy. Potassium ion concentrations were determined by atomic absorption spectophotometry.

Ammonium ion concentrations were determined by adding sodium hydroxide to the sample and then steam distilling the resulting ammonium gas. Nessler reagent was added to the distillate and ammonia was then determined calorimetrically.

Bacterial nitrogen determinations were performed in the following manner: The sample containing the bacteria was digested in sulphuric acid according to the Kjeldahl method[34]. The digestion of the sample was performed in the presence of potassium ions and mercuric ions, approximately 8 ml of concentrated sulphuric acid, and 100 ml of deionized water. The broth was heated for at least an hour, after which all the water had been evaporated and the remaining sulphuric acid boiled.

It was observed that digesting conditions were so severe that, where solid sulphide was present in the sample, this had partially dissolved leaving a yellow precipitate (presumably sulphur). In this digestion process, all nitrogen present in bacteria was converted to ammonium ions (due to the very high acidity of the

broth). The residue from the digestion was then diluted to a known volume with deionized water, and sent for the ammonium ion determination as set out before.

Ferrous ion concentrations were determined by titrating one ml of the solutions of the respective samples with 0,01791 N potassium dichromate solution. This was done in the presence of sodium diphenylamine sulphonate indicator, sulphuric and phosphoric acid, to a purple endpoint. Sometimes barium diphenylamine sulphonate was used as the indicator, leading to comparable results.

Ferric ion determination by titration with sodium thiosulphate solution in the presence of potassium iodide proved not to yield reproducable results. These seemed to vary with the length of time the solution had stood before the actual titrations were performed. It was therefore decided to determine the total iron concentration and then obtain the ferric ion concentration by deducting the ferrous ion concentration.

Total iron concentration was also determined by adding a solution of phosphoric, sulphuric, and hydrochloric acid to a 1 ml sample, and reducing the ferric ions to their ferrous state over heat using stannous chloride. After adding saturated mercuric chloride solution the mixture was titrated as with ferrous ion determination in the presence of barium diphenylamine sulphonate indicator. These results were found to be reproducable. Ferric ion concentrations could then be obtained by subtracting the ferrous ion concentration from the total iron concentration.

3.5. RESIDUE ANALYSIS

Samples from the bioleaching and chemical leaching of Ni_3S_2 in experiments of Type C were analyzed and compared. Polished sections were prepared of each sample. These were examined by optical microscopy using reflected light, to determine the leaching features of the particles.

X-ray diffractograms were run of the polished sections to determine qualitatively the type and relative amounts of phases present in the leached samples.

Scanning electron microscopy was used to confirm the composition of the phases and to examine the leaching features at higher magnifications. The electron microprobe was also used in an attempt to determine the composition of some of the phases.

3.6. PROCEDURES

The procedure followed in experiments of Types A, B, C and D are presented in Sections 3.6.1, 3.6.2, 3.6.3, and 3.6.4 respectively. Details on the nature of the experiments and the location of relavant material are summarized in Tables 1.1 and 1.2.

3.6.1. DETERMINATION OF EFFECTS OF NUTRIENTS, OXYGEN AND BACTERIA ON REDOX POTENTIAL IN ABSENCE OF NICKEL SULPHIDE

Five tests of Type A were carried out in the stirred reactors, all with the following common conditions: Initial reactor volume of 1,5 litre containing 67,2 g $FeSO_4.7H_2O$ (resulting in a 9 g/l concentration of ferrous ions); pH controlled at 1,6 (±0,5) by the addition of a 200 g/l sulphuric acid solution; and temperature controlled at 37,0(±0,2)°C. In each test, ferrous and ferric levels and the redox potential were measured intermittently for progressively more iron in the ferric state.

In Tests A.1 and A.2 neither nutrients nor bacteria were added. Ferrous ion oxidation to ferric ion was accomplished by the gradual addition of 30% (by mass) hydrogen peroxide, with aeration and nitrogen purging respectively. Tests A.3 and A.4 were similar to Tests 1 and 2, but 10% of the 9K nutrient concentrations was added at the beginning of each of the tests.

In Test A.5 a bacterial culture adapted to ferrous ion growth (see Appendix A.2.3.1) and $1/10^{th}$ of the 9K nutrient concentrations were added. No hydrogen peroxide addition was required as the bacteria gradually oxidized the ferrous ions.

3.6.2. DETERMINATION OF ELECTROCHEMICAL MODEL CONSTANTS OF NICKEL SULPHIDE SYSTEM IN ABSENCE OF BACTERIA

In Experiments of Type B, also conducted in a stirred reactor, the redox potentials were kept constant by the automatic addition of hydrogen peroxide (30% by mass). Experiments were performed at 500, 450, 400, and 300 mV (vs the SCE at 37°C centigrade). 20 g of Ni_3S_2 and 1,5 l of a 9 g/l iron sulphate solution were added to the reactor. No nutrients were included as these experiments were sterile (i.e. no bacteria were present).

Due to the short duration of the test (8 hours), strict aseptic technique was not applied. The possibility of any bacterial contamination from the surroundings was minimal at any given time, and if it did occur, the time spans of the experiments were not long enough to allow any significant bacterial growth. The humidifiers were maintained at 37°C in order to inhibit the loss of water from the system. The samples were analyzed for nickel ions. pH levels were initially adjusted to 1,6 using a 200 g/l sulphuric acid solution. Liquid samples were taken at 1, 4, and 8 hours (after allowing the slurry to settle for approximately 5 minutes each time).

3.6.3. DETERMINATION OF BIOLEACHING CHARACTERISTICS OF NICKEL SULPHIDE

As the time spans of the five parallel tests of Type C were relatively long, semi-aseptic technique was followed in order to avoid contamination (see Appendix A.2.4.1). This was especially so for sterile controls (where no bacteria were added). Two parallel stirred reactors, at 37°C, were used in this part of the testwork. Airflow at approximately 0,9 l per minute was metered through rotameters into the humidifiers.

A control system was devised such that the redox potential in the sterile control was maintained at the same level as that in the inoculated system at any given time. This was achieved by the addition of a 30% by mass hydrogen peroxide solution to the sterile system. The control system was operative throughout the run. As the ferrous levels decreased towards the end of the tests the peroxide was diluted threefold, as it was found that one drop of 30% peroxide resulted in significant overshoot of redox potential in the sterile vessel.

Initially, only a 1,50 l solution, containing $1/10^{th}$ of the 9K nutrients and 9 g/l of ferrous ions and a pH level of 1,6, was added to each vessel. At the start of the run, the one system was inoculated with bacteria, and 0,05 g of mercuric chloride was added to the other system which was to serve as the sterile control. Mercuric chloride inhibits oxidation of reduced sulphur compounds by bacteria[11]. The development of the bacterial culture utilized is described in Appendix A.2.3.2. The bacteria were left to oxidize the ferrous

iron for a few hours. This not only exhibited their activeness, but also prevented the redox potential from dropping too low in the initial period of leaching after the addition of 20 g of pure Ni_3S_2. This might have led to the evolution of hydrogen sulphide, resulting in the leaching not taking place by ferric ions. Results might then not have been reproducable for a given experiment, as the amount of hydrogen sulphide generated would have been difficult to quantify.

A 200 g/l sulphuric acid solution was used to adjust pH levels. During the experiments, the humidifiers were left at room temperature. This was done because the time spans of the experiments were so long that some changes in the amount of water in the systems were bound to occur. It was therefore decided to make up for the loss of water vapour just before sampling took place on a daily basis. Markings were made on the vessels to indicate the level of pulp after removing 1, 2, 3, etc. samples to determine the amount of water to be added to make up for evaporation losses. (Thus the addition of sulphuric acid also served to partially replenish the water lost as vapour.) Any solids adhering to the sides of the vessel were washed back into the pulp at the same time. Sterilized water was used in this procedure. The calomel electrodes were replaced with cleaned electrodes at the same time.

After adjusting the pulp levels, a 30 ml samples of pulp were taken on a daily basis from the sterile and from inoculated systems. The pulp was first repeatedly sucked up in the syringe and returned to the reactor, just before the actual sampling took place. This was to try and obtain a representative slurry in the tube through which the sample was taken. Each sample was

taken in about 3 seconds. Preliminary tests (weighing solids obtained by sampling from a known pulp density) showed that approximately 80% of the expected solid mass was obtained in sampling in this way. It is presumed that the solid which preferentially stays behind in the reactor is that which has the larger particle sizes, and that the extraction of nickel in the reactor is not affected to a significant degree by the slightly imperfect sampling procedure.

All samples were washed with slightly acidified water. Every second washed residue of the systems was subsequently acid leached (in a strong HCl solution to remove ferric precipitates), rewashed, and digested for organic nitrogen determination (as described in Section 3.4). The sterile residues, however, were not digested for organic nitrogen determination. The washing and acidic leaching processes are described in more detail in Appendix A.2.4.2. Digestion of a Ni_3S_2 sample in the absence of bacteria was found to yield no detectable amount of ammonium ions. Thus only bacterial nitrogen contributed to the nitrogen content of the residue, as jarosite nitrogen had been removed by the acid leaching step.

The supernatant of the sample was analyzed for iron, nickel, phophorus, magnesium, potassium, ammonium, and sulphate. The number of bacteria in the supernatant of the inoculated system was determined daily. The counting procedure followed is presented in Appendix A.2.4.3. The acid extract obtained every second day was analyzed for iron, nickel, potassium, and ammonium ions.

In order to write a balance for ammonium in the system, it was necessary to know how much nitrogen was present in a single bacterium. In order to obtain an estimate of this amount, the bacteria were harvested by centrifugion at the end of Test C.5, and washed to remove nitrogen remaining in the solution. After counting the number of bacteria, 30 ml of a washed bacterial suspension was digested as described in Section 3.4. Therefore the equivalent mass of ammonium ions per bacterium (the amount of ammonium ions required to form one bacterium) could be estimated.

3.6.4. DEDUCTION OF EFFECT OF HYDROGEN PEROXIDE ON LEACHING OF NICKEL SULPHIDE IN ABSENCE OF BACTERIA

Two sterile experiments of Type D were conducted in stirred reactors without the addition of hydrogen peroxide, i.e. allowing the redox potential to vary as leaching took place. As the time span of these tests was quite long, a semi-aseptic technique was also followed in order to avoid contamination. Details of the aseptic technique are presented in Appendix A.2.4.1. Airflow at approximately 0,9 l per minute was metered through a rotameter into the humidifier, which was left at room temperature as in the experiments of Type C.

A 1,5 l ferric solution, with a pH level of 1,53, was added to each vessel. These solutions contained no 9K nutrients (as the tests were sterile) and 9 g/l of ferric ions. A 200 g/l sulphuric acid solution was used to adjust pH levels halfway through the experiments. An amount of 10 g of Ni_3S_2 was added to each flask.

Level adjustment and sampling were performed in a manner similar to the procedures followed for the Type C experiments, and for similar reasons. The daily 30 ml slurry samples were centrifuged at 3500 rpm for 20 minutes. The supernatant was removed and the remaining wet solid was washed with 30 ml acidified water, centrifuged to remove most of the wash water, and dried. Ferrous, ferric nickel, and sulphate ion concentrations in the supernatant were determined.

4. RESULTS

The results of Experiments of Type A, B, C and D are given in Sections 4.1, 4.2, 4.3, and 4.4 respectively. For further details of the relevant experiments, see Tables 1.1 and 1.2 respectively.

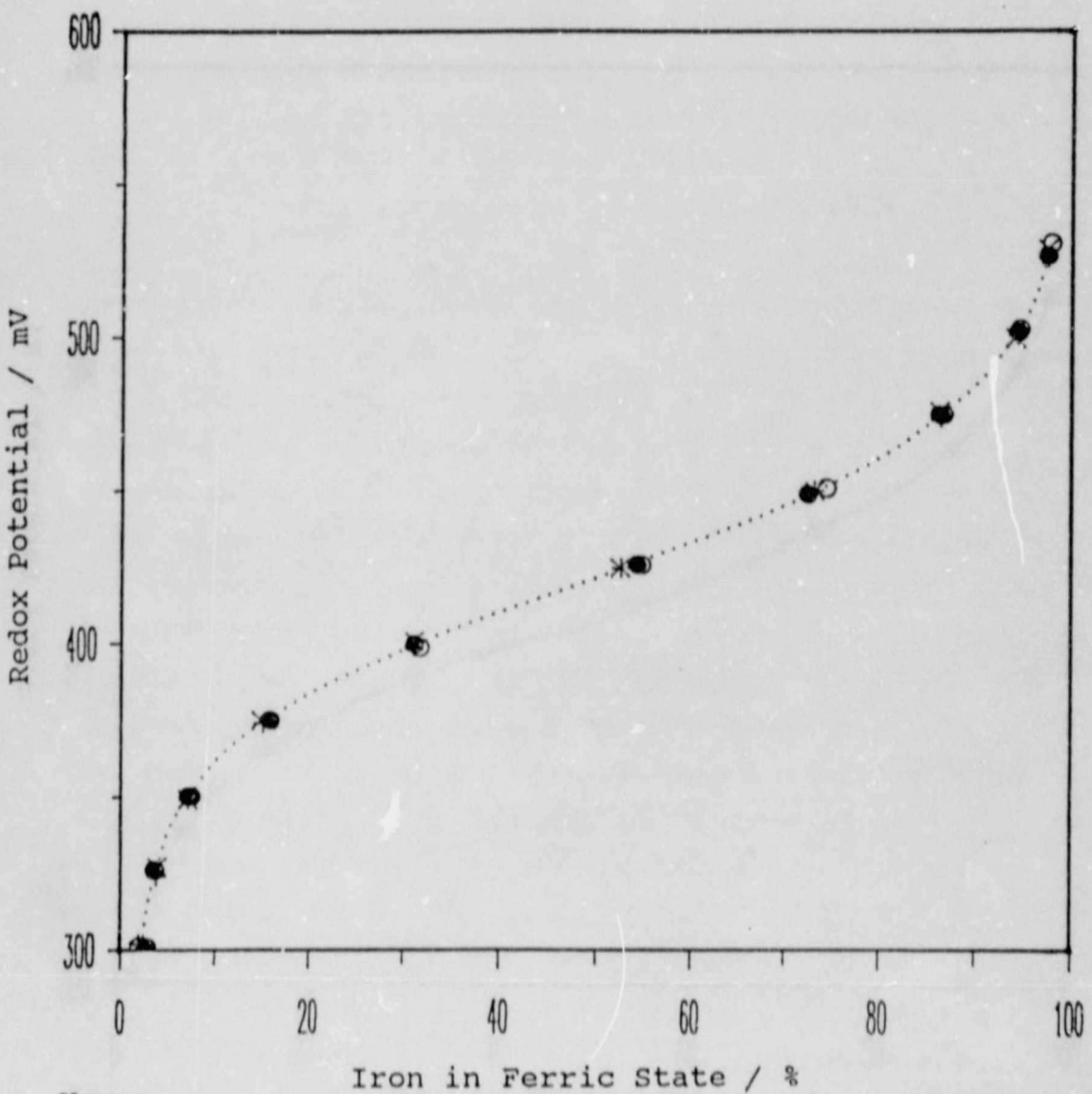
4.1. EFFECTS OF AERATION, NUTRIENTS AND BACTERIA ON REDOX POTENTIAL IN ABSENCE OF NICKEL SULPHIDE

The results presented in this sub section are from 5 experiments of Type A. These experiments utilized acidic iron sulphate solutions (pH 1,6), and the ferrous to ferric ion ratios were varied in each experiment. No nickel sulphide was present in these tests.

Five tests were conducted to determine the effects of $1/10^{th}$ of the 9K nutrients, aeration and the presence of bacteria on the redox potential of a solution. Basic experimental data of Tests A.1 to A.5 can be obtained from Appendix A.3.1 (Tables A.14 to A.18). The results of Tests A.1 to A.4 are summarized in Figure 4.1. It can be seen that, within experimental error, aeration and the presence of $1/10^{th}$ of the 9K nutrients had little effect on the redox potential under the given conditions. In Figure 4.2, the average result of Tests A.1 to A.4 is compared with Test 5, the test in the presence of bacteria. The two graphs appear to be approximately equal, thus it seems as if the presence of bacteria had little effect on the redox potential.

FIGURE 4.1.

Effects of Aeration and Nutrients on Redox Potential in Absence of Ni_3S_2. (Experimental Conditions: 9 g/l Soluble Iron; pH Levels of 1,6 and Temperatures of 37°C.)



Key :

x Aerated (No Nutrients), Test A.1

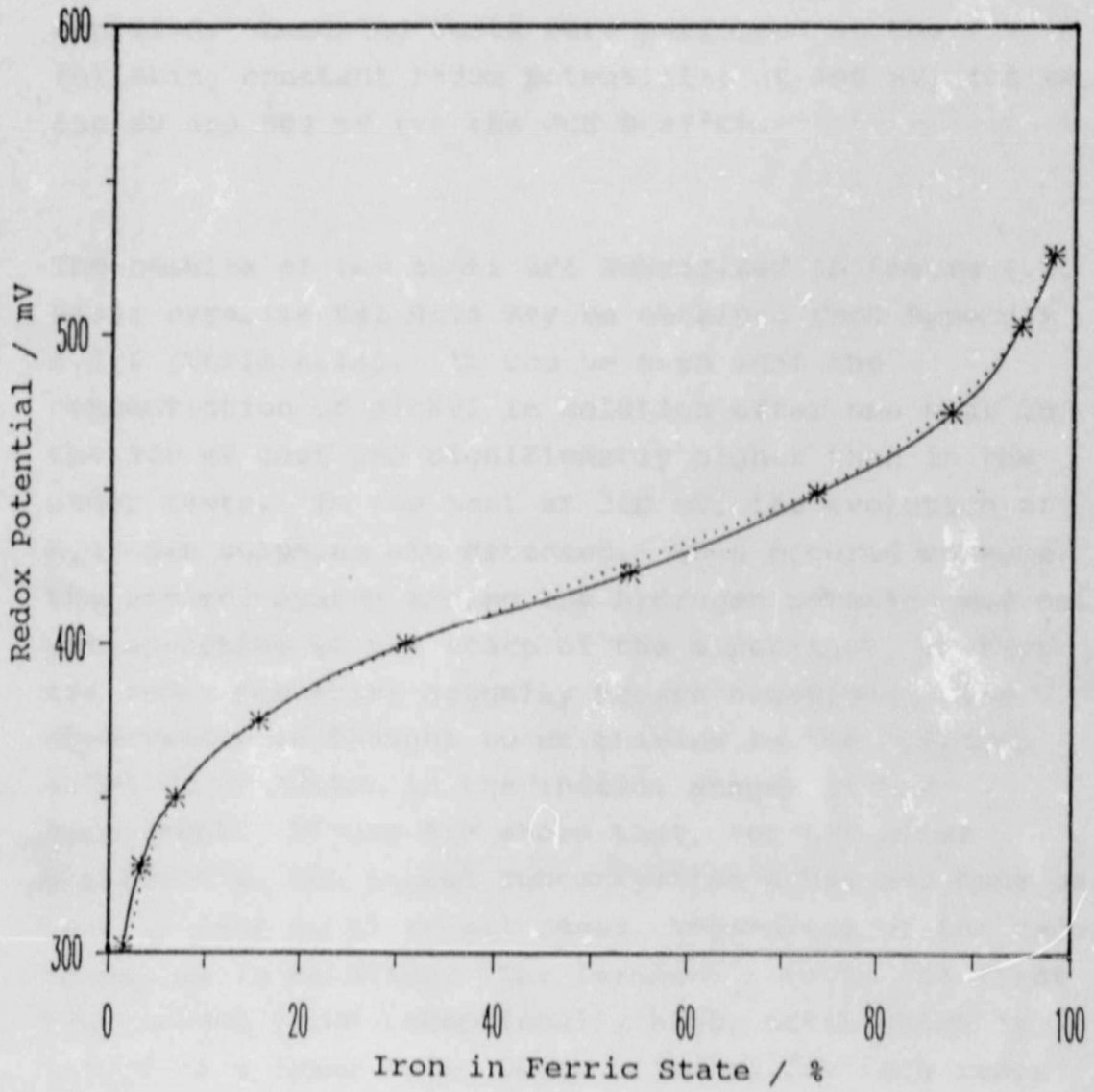
\+ Purged With N_2 (No Nutrients), Test A.2

• Aerated & Nutrients, Test A.3

o Purged With N_2 & Nutrients, Test A.4

FIGURE 4.2.

Effect of Presence of Bacteria on Redox Potential in Absence of Ni_3S_2. (Experimental Conditions: 9 g/l Soluble Iron; pH Levels of 1,6 and Temperatures of 37°C.)



Key :

-*- Ferrous Oxidation by Bacteria, Test A.5.

''' Average of Tests A.1 to A.4

4.2. EFFECT OF REDOX POTENTIAL ON NICKEL SULPHIDE LEACHING IN ABSENCE OF BACTERIA

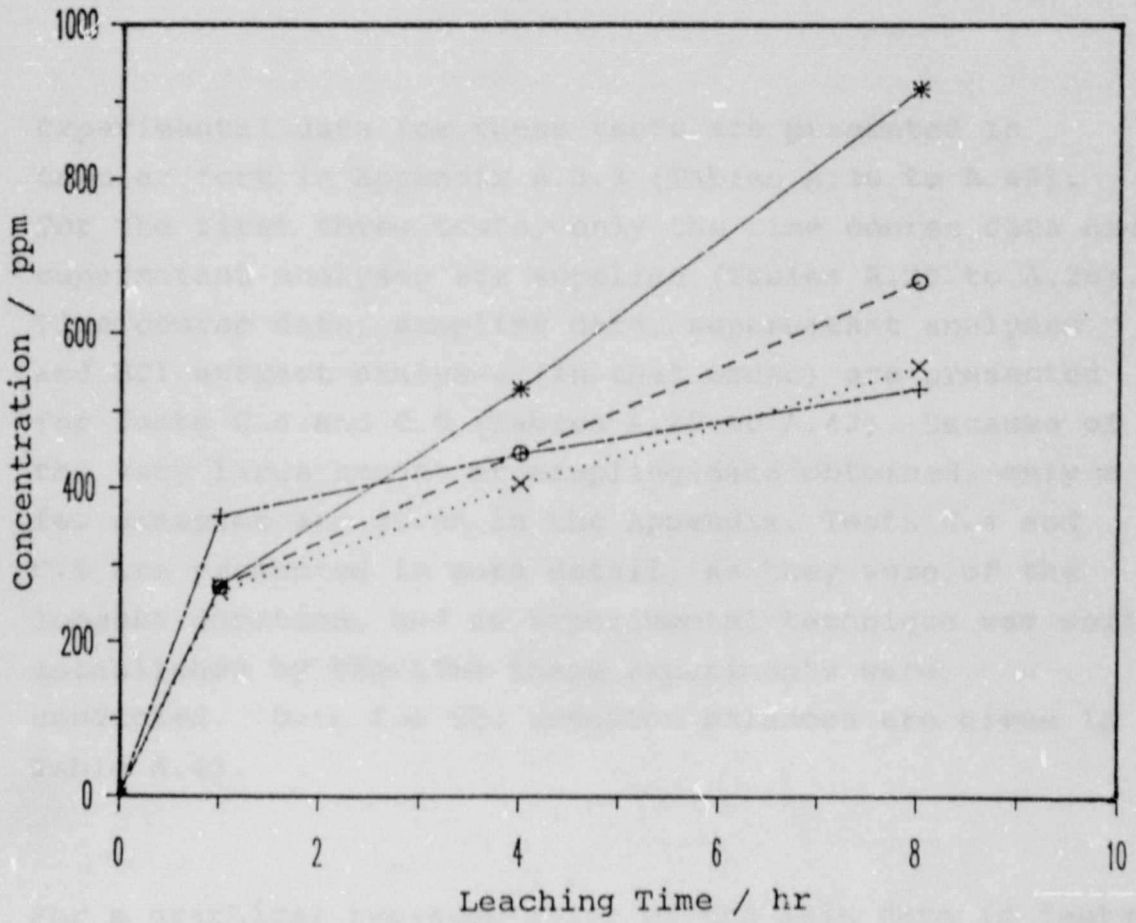
The results presented in this sub section are from 4 experiments of Type B. These experiments were performed at various fixed redox potentials. The tests were not inoculated with bacteria nor were any nutrients supplied. Leaching tests were performed at the following constant redox potentials: at 300 mV, 400 mV, 450 mV and 500 mV (vs the SCE @ 37°C).

The results of the tests are summarized in Figure 4.3. Basic experimental data may be obtained from Appendix A.3.2 (Table A.19). It can be seen that the concentration of nickel in solution after one hour in the 300 mV test was significantly higher than in the other tests. In the test at 300 mV, the evolution of hydrogen sulphide was detected. This occured because the control system adding the hydrogen peroxide was not yet operative at the start of the experiment, so that the redox potential actually became negative. This observation is thought to be coupled to the hydrogen sulphide evolution in the initial stages of the experiment. Figure 4.3 shows that, for the other experiments, the nickel concentration after one hour was more or less equal in all cases, regardless of the redox potential in solution. The leaching rate in the first hour seemed to be exceptionally high, after which it slowed to a lower rate, which differed for each redox potential. (The same pattern was followed by hydrogen peroxide consumption: the rate of addition was high in the first hour of the leaches, after which it settled at a lower steady rate). This led to the supposition that

a nickel deficient layer was formed around each particle in the first hour of leaching.

FIGURE 4.3.

Effect of Redox Potential on Leaching of Ni_3S_2 in Absence of Bacteria. (Experimental Conditions: 9 g/l Soluble Iron; pH Levels of 1,6 and Temperatures of 37°C.)



Key :

* Redox Potential Controlled at 500 mV, Test B.1

o Redox Potential Controlled at 450 mV, Test B.2

x Redox Potential Controlled at 400 mV, Test B.3

\+ Redox Potential Controlled at 300 mV, Test B.4

4.3. LEACHING CHARACTERISTICS OF NICKEL SULPHIDE IN PRESENCE AND ABSENCE OF BACTERIA

The bioleaching of Ni_3S_2 and the parallel sterile control was investigated in five tests of varying time span (Tests C.1 to C.5). In the parallel sterile control the redox potential was continually adjusted to that in the inoculated system by the addition of hydrogen peroxide.

Experimental data for these tests are presented in tabular form in Appendix A.3.3 (Tables A.20 to A.43). For the first three tests, only the time course data and supernatant analyses are supplied (Tables A.20 to A.28). Time course data, sampling data, supernatant analyses and HCl extract analyses (in that order) are presented for Tests C.4 and C.5 (Tables A.29 to A.42). Because of the very large amount of sampling data obtained, only a few examples are given in the Appendix. Tests C.4 and C.5 are presented in more detail, as they were of the longest duration, and as experimental technique was well established by the time these experiments were conducted. Data for the ammonium balances are given in Table A.43.

For a graphical representation of the main data in Tests C.4 and C.5, Appendix A.3.5 (Figures A.7 to A.26) may be consulted. Some of the more important features of the leaching of Ni_3S_2 are presented and discussed here. Redox potentials, nickel recoveries, iron concentrations, and ammonium and potassium concentrations are discussed respectively. Acid consumptions of the

systems are also discussed. Finally, a section is set aside for a discussion of the residue analyses.

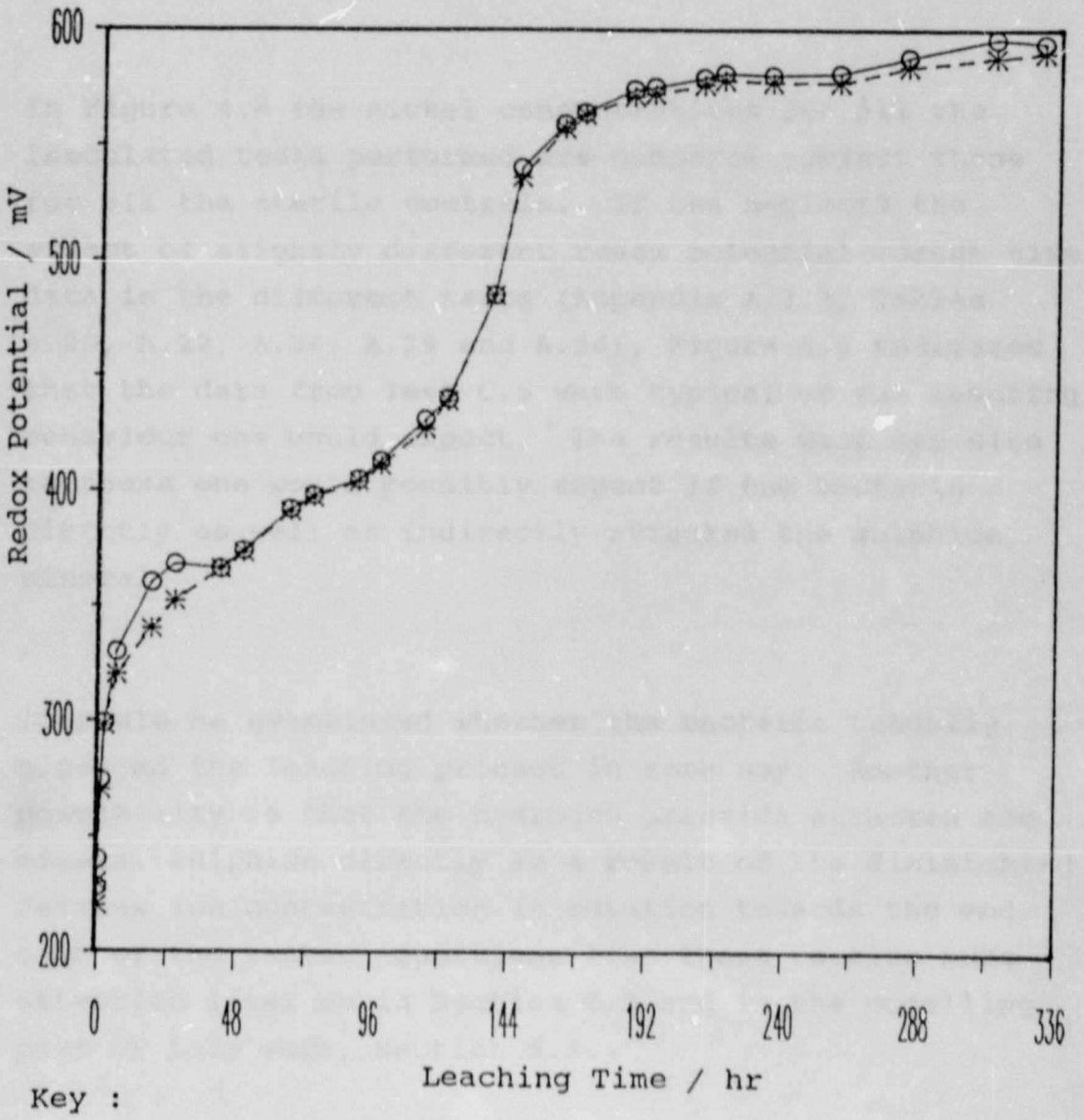
4.3.1. CHANGE IN REDOX POTENTIALS DURING LEACHING

Figure 4.4 shows the variation in value of the redox potential in the inoculated system and the sterile control (where the redox potential was continually adjusted to the value in the inoculated system). The slight 'hiccup' in the initial stages of the sterile control was due to accidental addition of too much hydrogen peroxide to the system, but this is not thought to have influenced the course of the experiment significantly.

The redox potential in the inoculated system increased with time as bacteria oxidized ferrous ions to ferric ions at a faster rate than ferric ions were consumed in the leaching of Ni_3S_2. Towards the end of the test, the ferrous ion concentration was lower, so that the oxidation rate of ferrous ions by bacteria decreased. This follows from Michaelis-Menten kinetics (provided in Appendix A.1.2, Equation A.3). Thus the redox potential remained more or less constant after a certain time.

FIGURE 4.4.

Test C.5, Variation of Redox Potential (vs SCE @ 37°C) with Time in Bioleaching of Ni_3S_2 and Parallel Sterile Control. (Experimental Conditions: Impellor Speeds 300 r.p.m.; 9 g/l Soluble Iron; pH Levels of 1,6 and Temperatures of 37°C; H_2O_2 added to Sterile Control so that Redox Matches That of the Inoculated System.)



Key :

o Sterile System

* Inoculated System

4.3.2. EXTRACTION OF NICKEL DURING LEACHING

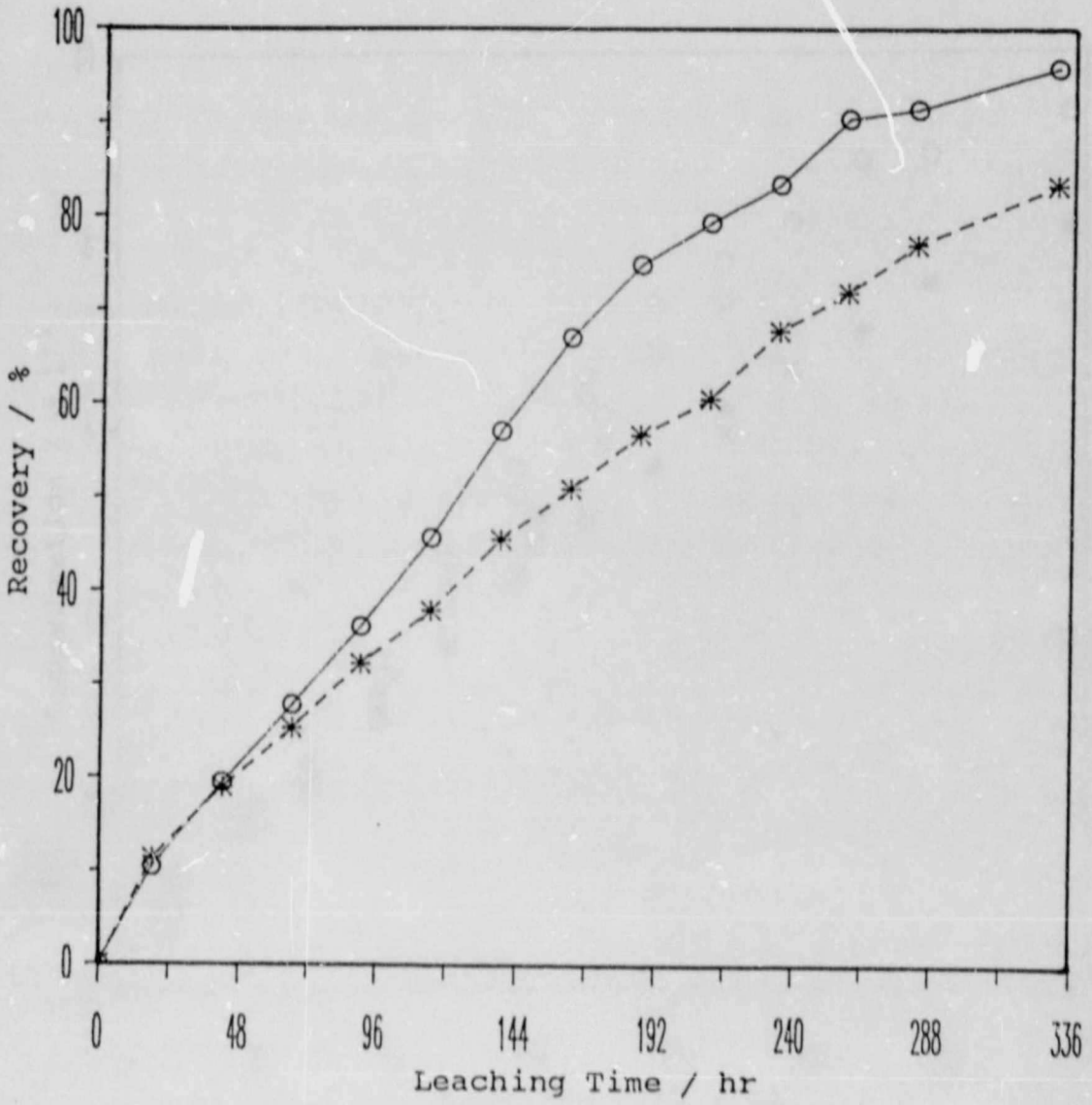
The nickel recoveries in the inoculated and sterile vessels for Test C.5 are given in Figure 4.5. A recovery of 100% represents a nickel concentration of 9,77 g/l. In the first four days the nickel concentrations were more or less equal in both systems. After that, the sterile concentrations increased significantly above that of the inoculated concentrations.

In Figure 4.6 the nickel concentrations for all the inoculated tests performed are compared against those for all the sterile controls. If one neglects the effect of slightly different redox potential versus time data in the different tests (Appendix A.3.3, Tables A.20, A.23, A.26, A.29 and A.36), Figure 4.6 indicates that the data from Test C.5 were typical of the leaching behaviour one could expect. The results were opposite to those one would possibly expect if the bacteria directly as well as indirectly attacked the sulphide mineral.

It could be questioned whether the bacteria actually hindered the leaching process in some way. Another possibility is that the hydrogen peroxide attacked the mineral sulphide directly as a result of the diminishing ferrous ion concentration in solution towards the end each of the tests. Questions like these receive more attention later on in Section 4.3 and in the modelling part of this work, Section 5.3.

FIGURE 4.5.

Test C.5, Nickel Recoveries vs Time in Bioleaching of Ni_3S_2 and Parallel Sterile Control. (Experimental Conditions: Impellor Speeds 300 r.p.m.; 9 g/l Soluble Iron; pH Level of 1,6 and Temperature of 37°C).



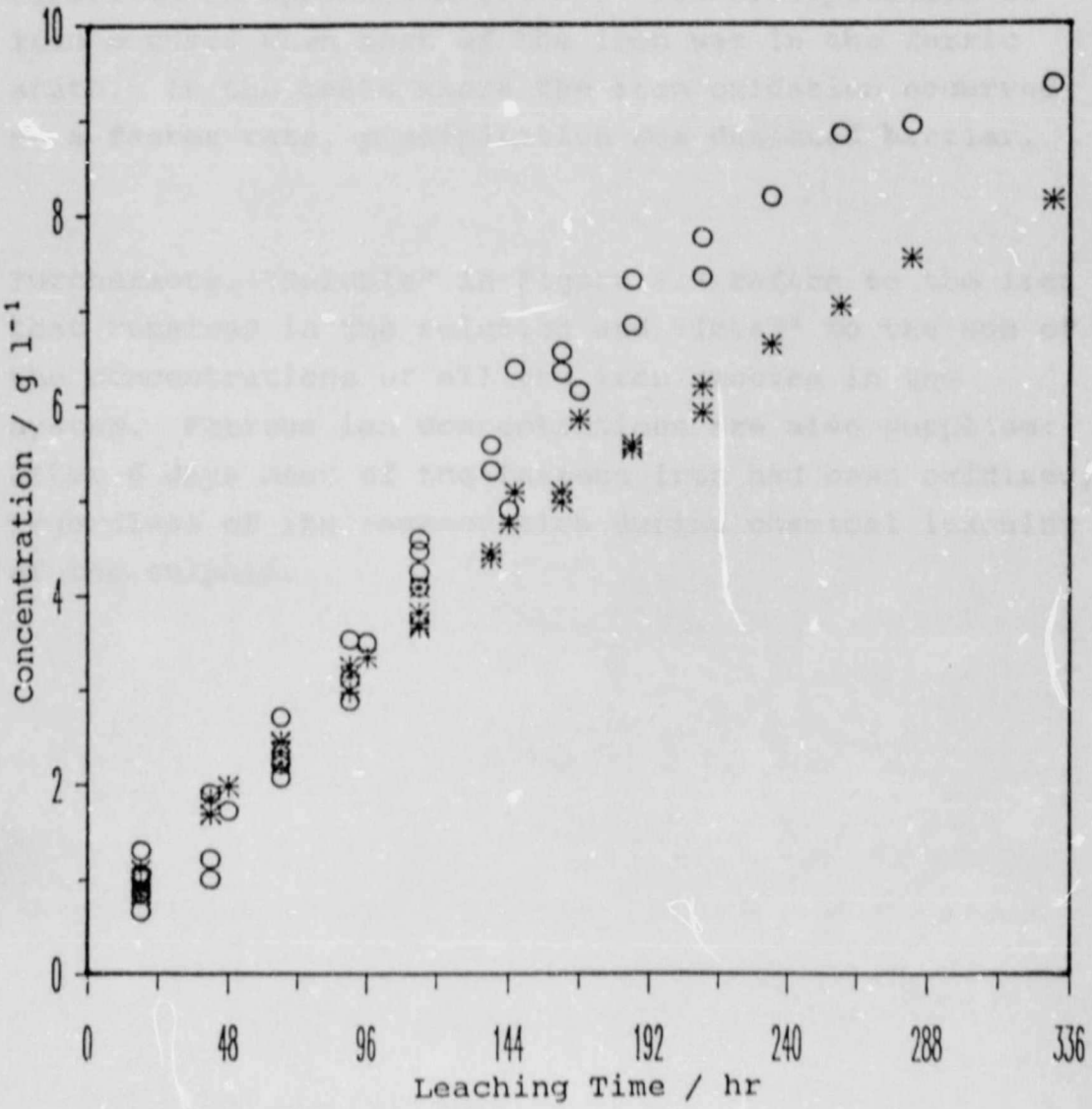
Key :

o Sterile System

* Inoculated System

FIGURE 4.6.

Tests C.1 to C.5, Nickel Concentrations vs Time in Bioleachings of Ni_3S_2 and Parallel Sterile Controls. (Experimental Conditions: Impellor Speeds 300 r.p.m.; 9 g/l Soluble Iron; pH Levels of 1,6 and Temperatures of 37°C.)



Key :

o Sterile Systems

* Inoculated Systems

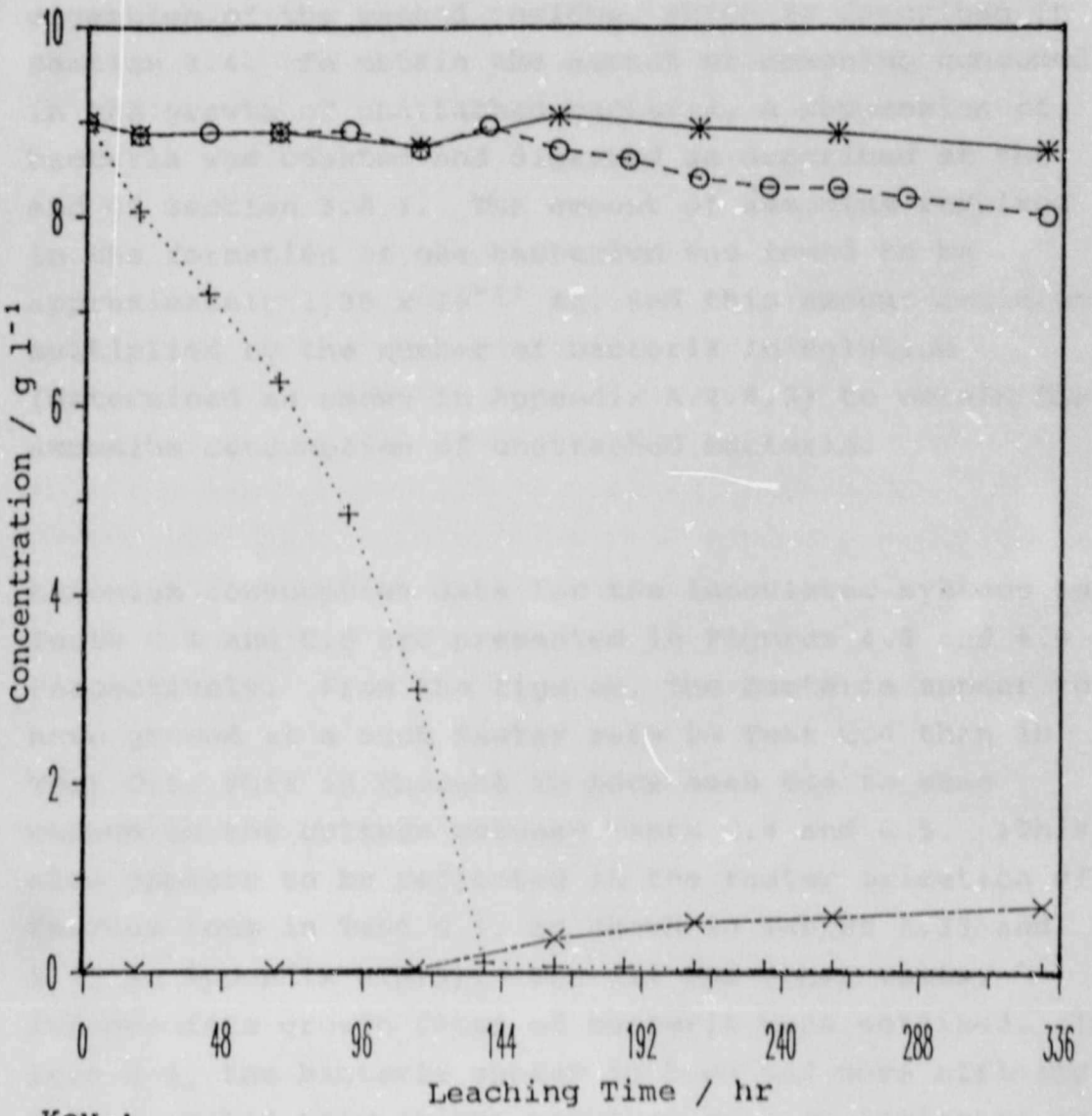
4.3.3. CHANGE IN IRON CONCENTRATIONS DURING LEACHING

The various iron species for the inoculated system in Test C.5 are given in Figure 4.7 as a function of leaching time. The data obtained was typical of that observed in other tests of Type C and their sterile controls. In the figure, "Precipitated" refers to the ferric ions present as jarosite (this concentration was estimated by the HCl extraction of the residue as described in Appendix A.2.4.2). The precipitation of iron occured when most of the iron was in the ferric state. In the tests where the iron oxidation occurred at a faster rate, precipitation was detected earlier.

Furthermore, "Soluble" in Figure 4.7 refers to the iron that remained in the solution and "Total" to the sum of the concentrations of all the iron species in the system. Ferrous ion concentrations are also supplied: after 6 days most of the ferrous iron had been oxidized, regardless of its regeneration during chemical leaching of the sulphide.

FIGURE 4.7.

Test C.5, Iron Balance in Bioleaching of Ni_3S_2. (Experimental Conditions: Impellor Speed 300 r.p.m.; 9 g/l Soluble Iron; pH Level of 1,6 and Temperature of 37°C).



Key :

* Total Iron Concentration

0 Soluble Iron Concentration

x Precipitated Iron Concentration

\+ Ferrous Concentration

4.3.4. CHANGE IN AMMONIUM AND POTASSIUM CONCENTRATIONS DURING LEACHING

In order to obtain an ammonium balance for the system, it is required to know the amount of ammonium consumed in the growth of bacteria. For bacteria attached to the mineral, this amount may be obtained directly from the ammonium ion determination after sulphuric acid digestion of the washed residue, which is described in Section 3.4. To obtain the amount of ammonium consumed in the growth of unattached bacteria, a suspension of bacteria was counted and digested as described at the end of Section 3.6.3. The amount of ammonium required in the formation of one bacterium was found to be approximately $1,39 \times 10^{-11}$ mg, and this amount could be multiplied by the number of bacteria in solution (determined as shown in Appendix A.2.4.3) to obtain the ammonium consumption of unattached bacteria.

Ammonium consumption data for the inoculated systems in Tests C.4 and C.5 are presented in Figures 4.8 and 4.9 respectively. From the figures, the bacteria appear to have growed at a much faster rate in Test C.4 than in Test C.5. This is thought to have been due to some change in the culture between Tests C.4 and C.5. (This also appears to be reflected in the faster oxidation of ferrous ions in Test C.4, as shown in Tables A.33 and A.40 in Appendix A.3.3). For all the other tests, intermediate growth rates of bacteria were obtained. In Test C.5, the bacteria appear to have had more affinity for the solid than in the previous run, as indicated by the graphs for attached bacteria. However, bacteria seemed to attach to the solid in both Tests C.4 and C.5. The latter is an important observation, as it is

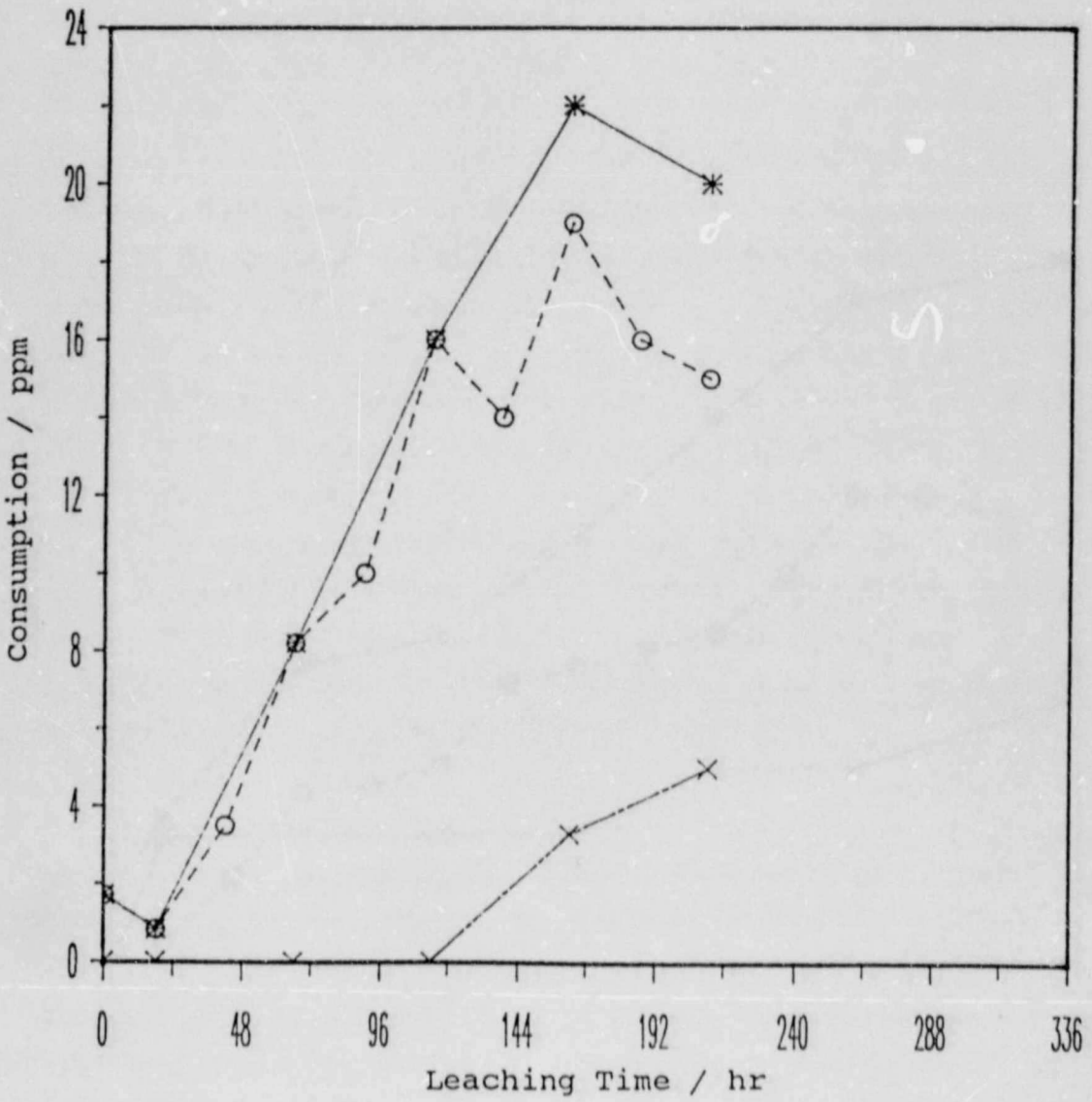
commonly accepted that the direct mechanism can occur only if the bacteria attach to the solid.

In Appendix A.3.5 (Figures A.15, A.16, A.19 and A.20), the ammonium balances for the sterile and inoculated systems in Test C.4 and C.5 are given (Nomenclature in the figures is similar to that of the iron balance in Figure 4.7). As the total ammonium concentrations were found to be more or less constant during the time span of the experiments (within experimental error), the results obtained for attached and unattached bacteria seemed to be reliable.

The data presented in Appendix A.3.5 (Figures A.11 to A.24) confirm that potassium ions precipitated as jarosite before ammonium ions followed suit, at least under the given conditions. Total potassium levels in solution can be observed to have to increased, probably due to leakage of electrolyte from probes. Jarosite precipitation in the sterile and inoculated systems appears to be similar.

FIGURE 4.8.

Test C.4, Ammonium Consumption in Bioleaching of Ni_3S_2. (Experimental Conditions: Impellor Speed 300 r.p.m.; 9 g/l Soluble Iron; pH Level of 1,6 and Temperature of 37°C.)



Key :

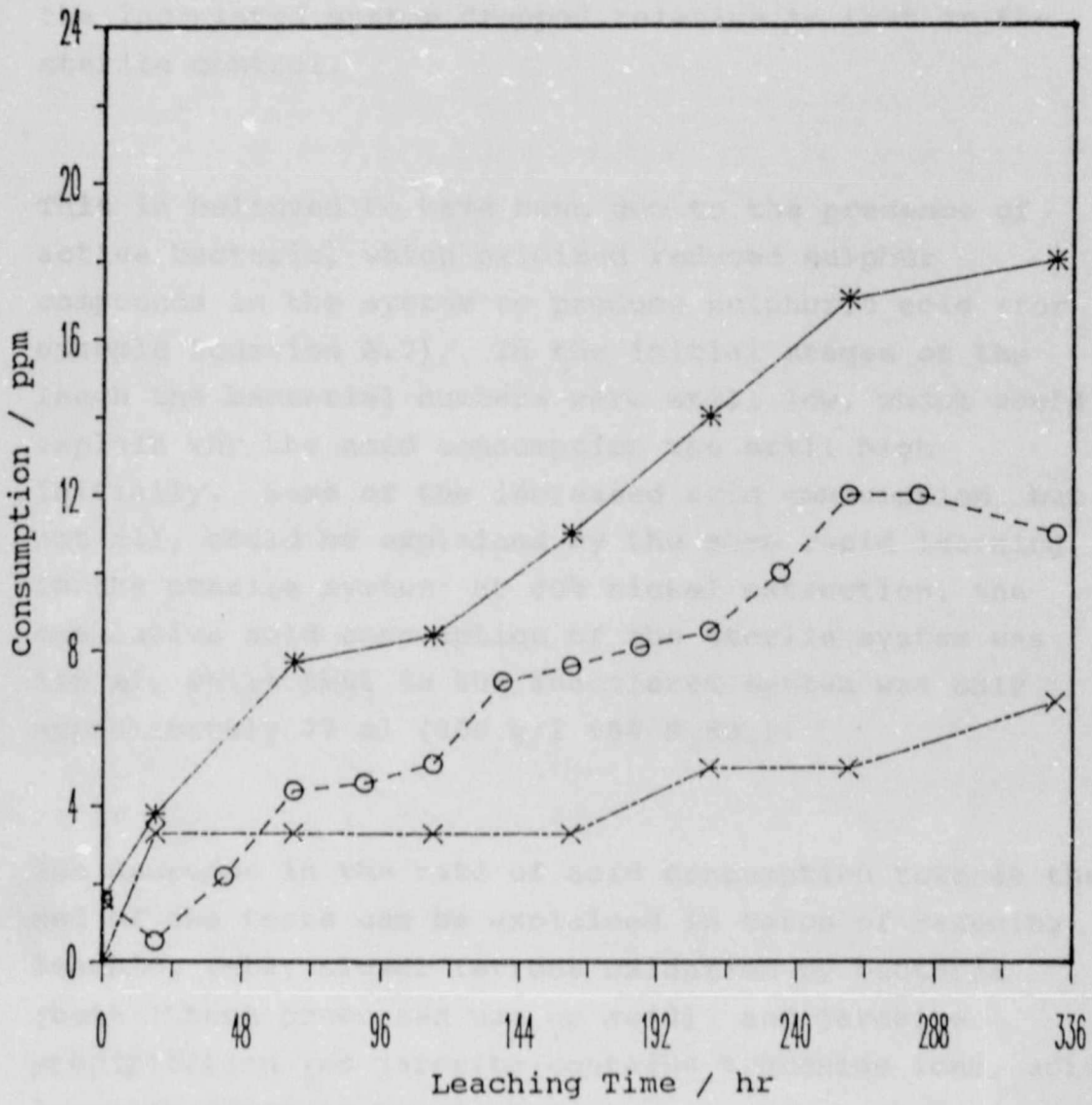
* Total Bacterial Consumption

o Ammonium Consumed by Unattached Bacteria

x Ammonium Consumed by Attached Bacteria

FIGURE 4.9.

Test C.5, Ammonium Consumption in Bioleaching of Ni_3S_2. (Experimental Conditions: Impellor Speed 300 r.p.m.; 9 g/l Soluble Iron; pH Level of 1,6 and Temperature of 37°C.)



Key :

* Total Bacterial Consumption

o Ammonium Consumed by Unattached Bacteria

x Ammonium Consumed by Attached Bacteria

4.3.5. ACID CONSUMPTIONS DURING LEACHING

The consumptions of 200 g/l sulphuric acid solution in the inoculated system and sterile control of Test C.5, required to maintain constant pH are compared in Figure 4.10. In the initial stages of the experiment, the acid consumptions in the parallel systems were more or less equal. However, after a few days, the consumption in the inoculated system dropped relative to that in the sterile control.

This is believed to have been due to the presence of active bacteria, which oxidized reduced sulphur compounds in the system to produce sulphuric acid (for example Equation A.7). In the initial stages of the leach the bacterial numbers were still low, which could explain why the acid consumption was still high initially. Some of the increased acid consumption, but not all, could be explained by the more rapid leaching in the sterile system: at 80% nickel extraction, the cumulative acid consumption of the sterile system was 115 ml, while that in the inoculated system was only approximately 77 ml (200 g/l 98% H_2SO_4).

The decrease in the rate of acid consumption towards the end of the tests can be explained in terms of reducing leaching rate, slower ferrous oxidation by bacteria (both these processes use up acid), and jarosite precipitation (as jarosite contains hydroxide ions, acid is released as it precipitates).

The reduced acid consumption in the inoculated system is of importance, as it has now been shown that bacteria in