

EXPERIMENTAL INVESTIGATIONS OF SOME FACTORS INFLUENCING  
THE UNDERGROUND LEACHING OF CHALCOPYRITE ORE

- A Preliminary Report -

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## ABSTRACT

Experimental investigations were carried out to establish a satisfactory technique and to study some factors--chalcopyrite to pyrite ratio, rate of flow, sulphuric acid acidity, and ferric sulphate--influencing the leaching of chalcopyrite ore.

Samples of two different ores--Fairview ore and selected high grade chalcopyrite specimen--taken from the Britannia Mine were leached with different chemical solutions at various rates of flow.

The results indicate the presence of pyrite and the chemical character of the reacting solutions are key factors in determining the order of magnitude of the leaching processes. Rate of flow is of secondary importance and becomes less significant with a low pyrite to chalcopyrite ratio. Weak sulphuric acid solutions greatly influence the rate of leaching; for the Fairview ore increasing the copper and zinc leached up to two hundred times. Leaching is not proportional to acidity above a certain level. Weak ferric sulphate solution appreciably increases the magnitude of leaching; increases five times the copper leached in the Fairview ore. The copper to zinc ratio remains reasonably constant, approaching unity for higher metal concentrations.

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INTRODUCTION:

Experimental work has been done to determine some of the factors influencing the rate of leaching of chalcopyrite ore under mine conditions. Experiments were carried out in the Biogeochemical Laboratory of the University of British Columbia, on samples taken from the Britannia Mine.

Four sets of apparatus were used to investigate the influence of the following factors over a limited range - mineralogical concentration of chalcopyrite and pyrite in the ore, rate of flow, sulphuric acid acidity and ferric sulphate. Experimental work was conducted in a manner so as to establish a satisfactory technique and to eliminate insignificant and unavoidable influences; only after this is reasonably accomplished can the major influences be usefully investigated and interpreted. In spite of limited time and range of experimentation some qualitative and quantitative hypotheses have been drawn. Because the work to date has been empirical, no theoretical approach to the project has been attempted. The writer expects to continue and to elaborate on the experimentation in the near future.

ACKNOWLEDGMENTS:

The writer wishes to thank the Britannia Mining and Smelting Company for suggesting and supporting the project and to the officials who cooperated in obtaining the samples and familiarizing the writer with the mine condition pertaining to the subject. All

the work has been carried out in the laboratory of the Department of Geology of the University of British Columbia. Special thanks are extended to Dr. R. L. Delavault who designed and made the apparatus and guided the writer in carrying out the experimental work.

#### METHOD:

The method chosen was to simulate as much as possible the conditions at the Britannia Mine. In general there are two sets of experiments with each set consisting of a sample of Fairview ore and of a selected high grade chalcopyrite sample. The leaching history of the two samples in each set is somewhat similar so that comparisons may be readily made for interpretation.

The ore samples were crushed and put in glass tubes (hereafter known as the ore tube) and attacked by different solutions (hereafter known as the heads) at different rates of flow. The reacted solutions (hereafter known as the tails) were collected daily irrespective of volume unless extreme rates necessitated it. The tails were then analyzed for copper and zinc and for iron where feasible. The concentrations are expressed in gammas per litre which is the equivalent of parts per thousand million.

The results have been plotted on graphs in a manner to illustrate best the effects of the known factors on the degree of leaching. No allowances were made for temperature as this would have involved costly equipment. Moreover, the range of temperature in the laboratory was not considered great enough to have an important influence on the interpretation of results. However, it should be noted that temperature has a direct influence on rate of chemical reactions and thus diurnal temperature variations may be responsible for many

minor unexplained changes in the degree of leaching. An adequate source of oxygen at the observed rate of weathering would be supplied by oxygen dissolved in the heads solutions and from the atmosphere. Chemical assays of ore were not considered to be essential, at least until the order of magnitude of the leaching had been established. Amounts leached from the ore are a negligible proportion of visible copper contents.

#### APPARATUS:

A complete unit of apparatus as assembled on the iron rod grid is shown in the diagram. The different parts are briefly discussed under the appropriate headings.

#### Glassware:

A complete set of glassware consists of a heads flask, a feeder decantor, an ore tube, and several tails containers.

The heads flask is a one litre flat-bottomed Florence flask to the neck of which have been attached two glass tubes - an outlet tube and an air intake tube. The latter is an inch longer than the former and is fitted with a stopcock to allow the flask to be mounted on the rack without spilling.

The feeder decantor is a one inch diameter vertical tube to which a "S" shaped smaller glass tube has been attached about two inches from the bottom of the larger tube. The smaller tube ends in an upwards capillary and is nearly obstructed by an inserted platinum wire (number 28 B & S gauge). By adjusting the length of platinum wire inserted in the capillary the rate of flow may be varied with the limits of 2 ml. per hour up to 200 ml. per hour. The first feeders used had a smaller glass capillary and no platinum wire but they were easily plugged by any small solid particles. After several weeks of trial and error the platinum wire technique was adopted. It combined the ad-

vantages of being easily and quickly flushed out in the event of plugging and allowed for regulation of the rate of flow.

The ore tube is a Pyrex glass tube, 36 inches long and one half inch in diameter. Near one end the glass has been pushed in and the indentations so formed act as stoppers for the ore and allow for the unobstructed passage of the reacted solutions.

The tails are gathered in 250 millimeter pyrex bottles equipped with a funnel.

Hardware:

The first experiments were assembled on two retort stands with the ore tube in a position of 25 degrees to the horizontal.

The experiments were later moved to the adjustable steel rod grid which was installed on the laboratory wall with the ore tubes in a near vertical position.

Buretts clamps and ring clamps are used to hold the pieces of apparatus on the grid. A two inch gap has been cut in the ring clamp holding the heads flask to allow for the removal of the flask without the necessity of lowering the clamp.

Chemicals:

The only chemicals used in the leaching processes are sulphuric acid and ferric sulphate. Desired normalities are made from a stock solution of concentrated chemically pure sulphuric acid. The stock ferric sulphate powder is factory assayed at 70 per cent with less than .02 per cent trace element content. Check tests proved that the ferric sulphate contained insignificant concentrations of copper and zinc within the limits of the experiments.

The chemical and procedure used in trace element analyzing are those used and described in the literature by the Biogeochemical laboratory of the University of British Columbia.

Ore Samples:

Two ore samples taken from the Britannia Mine were used in the experiments. Polished sections were made in order to make a rough estimate of the mineralogy and in particular the chalcopyrite to pyrite ratio.

The Fairview ore was taken from the second vein at the 1,000 foot level. Chalcopyrite, pyrite and minor amounts of covellite are the identified sulphide minerals with a chalcopyrite to pyrite ratio of about 2 to 1. An approximate copper assay of the Fairview ore would be about 1%. The gangue consists of quartz and schist country rock; no reactive carbonate gangue minerals were observed.

The high grade chalcopyrite sample has been selected to act as a control in establishing the major influences affecting the rate of weathering and to be used as a comparison to the more typical Britannia ore - the Fairview. The high grade sample consists almost entirely of chalcopyrite (90%) with some quartz and a little pyrite; the chalcopyrite to pyrite ratio is approximately 50 to 1.

The ore samples were crushed in the rock crusher of the Mining and Metallurgy Department, University of British Columbia through the courtesy of Mr. Howard. The size of the particles range from fine dust up to fragments measuring  $\frac{1}{4}$  of an inch, the average being  $\frac{1}{8}$  of an inch. The unsorted crushed ore was funnelled into the glass tube filling approximately 30 inches of its length and weighing about 220 grams.

LEACHING HISTORY

In describing the leaching history of the four experiments the writer has taken the liberty to interpolate the results to illustrate the concentration relations caused by the various known



factors. Reference to the graphs illustrates that there is very little stabilization, even in the rate of flow. However, to describe the factors influencing the rate of leaching some interpolation is necessary if the causes of the relative concentrations are to be assessed. As mentioned previously diurnal temperatures probably account for many of the minor deviations.

The leaching histories are grouped into two sets - pure water attack and acid and ferric sulphate attack.

#### Set 1 - Pure Water Attack

Fairview Ore - The Fairview ore sample was leached by distilled water for a period of 26 days at an average rate of 200 millilitres per day. The concentrations of copper were 7 gammas per litre the first day and steadily increased until they became uniform at about 16 gammas per litre. The zinc exceeded that of copper during the first few days but became less than copper with an average of 8 gammas per litre. The initial zinc over copper concentration is probably due to the zinc's greater solubility.

The rate of flow was slowed down to 75 millilitres per day but with no significant change in the concentrations of either the copper or the zinc.

The rate was speeded up to over 200 millilitres per hour and the concentrations dropped to 10 and 5 gammas per litre for copper and zinc respectively. During the fast attack the system was slowed down to less than 10 millilitres per hour for a period of 12 hours but no significant change in the concentrations took place. The results indicate that the rate has little or no effect over a short period but over a period of several days the faster the rate the lower the concentrations within the limits of 8 and 18 gammas per litre of copper.

The copper to zinc ratio remained fairly constant at about 2 regardless of the rate of flow.

In order to check if the concentration is a solubility phenomena the tails were recirculated ten times and samples taken of each recirculation. Both the copper and zinc concentration increased appreciably the first three times but then became stable at 24 gammas per litre for both copper and zinc. It appears that solubility is the major factor in limiting the amount of leaching for this given ore and given heads.

When turning over by 180 degree rotation the nearly horizontal tube, or changing its position from a more horizontal to a nearly vertical one, only a slight momentary increase in concentration occurred after which it resumed its normal magnitude.

No iron was detected in any of the tails solutions.

High Grade Chalcopyrite - The high grade chalcopyrite was attacked in a similar manner as the Fairview ore. Not until almost one litre had been passed through the sample over a period of four days was any copper detected. The copper concentrations then steadily increases until it became stabilized at around 30 gammas per litre. The zinc, as expected, showed an initial concentration of 10 gammas per litre but promptly fell to 5 and then increased to 14 gammas per litre. Unintentional changes in rate of flow or in complete stoppages due to plugging were markedly reflected in the concentration of both copper and zinc; the faster the flow the less the concentration.

After 20 days traces of iron were detected and gradually increased to 4 gammas per litre.

The rate was slowed down within the range 150 to 50 millilitres per day. The results emphasize the inverse relation of leaching to rate

of flow. The concentrations varied from 40 in the fastest to 200 in the slowest for copper and similarly from 20 to 140 for zinc. The rate was speeded up to 300 millilitres per day and the concentrations dropped from 200 to 16 for copper and from 140 to 13 for zinc.

In general the copper zinc ratio remained from 1 to 2.5 but showed considerable more fluctuation than in the Fairview.

A comparison to the Fairview leaching indicates the importance of the mineralogy of the ore in determining the magnitude of the factors influencing the rate of copper and zinc being picked up by the reacting solutions.

#### Set 2 - Acid and Ferric Sulphate Attack

Fairview Ore - The Fairview ore sample was attacked with a .02 N sulphuric acid solution at a rate of about 150 millilitre per day. The copper concentration quickly rose from 30 to 2700 gammas per litre within a few days and became relatively stable. The zinc increased from 200 to 600 gammas per litre and became stable. After an initial high copper to zinc ratio, it became uniform between 5 and 7. The tails had a faint blue color probably accounted for by the presence of copper bearing calcium sulphate. A light blue precipitate formed on the end of the ore tube and remained throughout the entire leaching history of the ore.

After two weeks the normality was increased ten times to a .1N sulphuric acid solution and the concentrations showed an immediate increase but after a few days settled back almost to the previous concentrations. The copper rose from 2000 to 5000 and stabilized at 2500 gammas per litre while the zinc increased from

550 to 1500 and stabilized at 1000 gammas per litre.

Only a trace of iron was detected in the tails solutions.

A hundredth of a mole of ferric sulphate was added to a litre of .1N sulphuric acid solution and the copper and zinc concentrations increased from 2,500 to 15,000 and from 1,000 to 10,000 gammas per litre respectively. As the rate was slowed down the concentrations both reached a concentration of 19,000 gammas per litre but when the rate was increased approximately 6 times the concentration dropped to about 9,000 and 7,000 for copper and zinc respectively.

The leaching emphasizes the important influence of the heads but it is not a direct relation and appears to be effective only to certain, yet unknown, limit. The rate of flow is of secondary importance and is effective only after an extended time - at least several days.

High Grade Chalcopyrite - The high grade chalcopyrite sample was leached with a .02N sulphuric acid solution for a period of 24 days. The copper concentration was fairly uniform with an upper limit of 280 and a lower limit of 150 gammas per litre. The wide range of fluctuation is accounted for by variations in the rate of flow and also by temperatures changes. The zinc, as in the other experiments, showed an initial high concentration but soon decreased to 30 gammas per litre from where it gradually increased to 100 gammas per litre. The copper zinc ratio fluctuated over a rather wide range of 1 to 7.

The iron concentration increased from 8 to 16 gammas per litre.

The normality was increased to .1N sulphuric acid and both the copper and zinc approximately doubled their concentrations

to 320 and 220 gammas per litre respectively.

One hundredth of a mole of ferric sulphate was added to the .1N sulphuric acid solution causing the concentrations to increase from 320 to 1100 for copper and from 220 to 1200 for zinc. Three days later the concentrations stabilized around 2800 and 2200 gammas per litre for copper and zinc respectively.

A small amount of light blue precipitate formed on the end of the ore tube when the copper concentration reached the order of magnitude of 3,000 gammas per litre.

The rate of flow was decreased to 2 millilitre per hour and the concentration of both copper and zinc increased to 3,600 gammas per litre, maintaining the copper zinc ratio of unity.

The heads was changed to pure water and within two days the concentrations dropped to less than 50 gammas per litre - the order of magnitude experienced in the water attack of the same type ore. This similarity of concentration witnessed in the pure water heads in the two experiments on the high grade chalcopyrite indicates the importance of the heads in determining the order of magnitude of the leaching processes. The rate of flow merely determines the range of fluctuation for a given concentrations which has been already established by the character of the heads solution.

Iron in the tails of the pure water heads dropped from 10 to 4 gammas per litre. This again exhibits a parallelism to the other high grade chalcopyrite experiment and further illustrates the importance of the heads, in determining the character of the tails.

#### COMPARISON OF RESULTS:

By comparing the results of the four experiments several

generalizations of the factors influencing the rate of leaching are noted.

The mineralogical composition, and in particular the concentration of pyrite, appears to be the key factor in determining the rate of chemical leaching for a given reacting solution. Pyrite - the so-called sparkplug of chemical weathering of ores - and not chalcopyrite is the important mineral in establishing the rate and the magnitude of copper and zinc going into solution. This is clearly illustrated by comparing the leaching histories of the two types of ore in each set. In the case of the water attack the time required for copper to be detected in the high grade sample bears evidence that the relative concentration of pyrite determines the speed of leaching, but with sufficient time the richer ore ultimately provides more copper than the leaner ore. Besides determining the order of magnitude of leaching the mineralogy also determines relative influence of rate of flow on the different types ore; in general pyrite concentration lessens the effect of changes in the rate of flow.

The rate of flow is shown to have an inverse effect on the rate of leaching as illustrated in the graphs by the antipathetic relation of the concentration curves and the rate of flow curve. This relation is not a direct one and depends on the mineralogy of the attacked ore. The high grade ore was considerably more sensitive to changes in the rate of flow than the Fairview. In the sulphuric acid and ferric sulphate attack the fluctuations caused by changes in rate of flow become less significant than in the water attack as the acid and ferric sulphate is not dependent on pyrite for their generation.

The copper zinc ratio for a given heads is fairly constant with the greater the leaching of copper and zinc the closer their concentrations approach one another. The zinc concentrations fluctuate much more than the copper and is probably explained by its greater solubility and by the analytical method used being more sensitive for zinc than copper. The high concentrations of zinc are rather surprising as no zinc minerals were observed in the polished sections, unless the zinc is contained in the chalcopyrite and its greater solubility allows it to be easily leached. The extent of the experimentation did not show any decrease in the zinc concentration with time.

The weak (.02N) sulphuric acid solution had a tremendous influence on both the rich and lean copper ore. It increased the concentrations of copper from those of pure water by about 200 times in the Fairview ore and about 10 times in the high grade chalcopyrite ore. However, by increasing the normality 5 times the concentrations in both ores increased only slightly which suggests that increasing acidity is effective only over a limited concentration range above which further increase is ineffective.

The addition of a hundredth of a mole per litre of ferric sulphate to a .1N sulphuric acid solution caused an extremely significant increase in the concentrations of copper and zinc. The Fairview increased by about 5 times and the high grade chalcopyrite by about 10 times. The greater increase in the ore lacking pyrite (high grade chalcopyrite) bears witness to the importance of pyrite in generating ferric sulphate as only a part of the ferric sulphate in the heads becomes effective in the

leaching process of the Fairview ore where there is considerable ferric sulphate present prior to that added by the heads.

Changing the position of the tube appears to have only a slight momentary effect on the degree of leaching which is probably accounted for by small portion of the ore at the top of the tube coming in contact with the solutions for the first time. For the size of tube and the rate of flows used in the experiments the position of the tube is not a major factor in determining the degree of leaching. The near vertical position offers less change for the solutions to channel along the lowest part of the wall of the tube and therefore reducing the surface area of ore in contact with the reacting solutions.

In examining the graphs it is noted that a change in heads was accompanied by an appreciable lower rate of flow. This unexpected change may be caused by the different viscosity of the heads solutions and the presence of a colloidal solution of ferric iron. These unavoidable changes plus the rate of flow fluctuations serve to emphasize that the technique is still in its experimental stage and many difficulties are yet to be ironed out if a simple and conclusive interpretation is to be made.

#### CONCLUSIONS:

The results, limited as they may be both in range of experimentation and in time and despite the numerous difficulties encountered (especially in trying to maintain a constant rate of flow), the following hypotheses are tentatively presented.

(a) The mineralogy and in particular the presence of pyrite is the key factor in determining the degree of leaching and es-



establishing the order of magnitude of copper and zinc going into solution. It becomes less significant when the ore is attacked by sulphuric acid and ferric sulphate solutions. The degree of influence of the other factors are dependent on the concentration of pyrite in the ore.

(b) The character of the attacking solutions determine the order of magnitude of leaching for a given type ore.

(c) The rate of flow determines the range of fluctuations in the leaching over a given magnitude which has been determined by the mineralogy of the ore and by the character of the attacking solutions. The concentration of copper and zinc going into solution varies inversely with the rate of flow, becoming less important with increased leaching. Ores carrying appreciable quantities of pyrite are less effected by the rate of flow than those having little or no pyrite.

(d) Weak sulphuric acid solutions (.02N) have a tremendous effect, 200 times the copper concentration for the Fairview ore, in increasing the rate of leaching. Its influence does not vary directly and becomes less significant for higher normalities (.1N).

(e) Weak ferric sulphate solutions (.01 moles per litre of .1N sulphuric acid solution) have a considerable influence (5 times the concentration of copper from the Fairview ore) on the leaching process. The influence is much less in ores carrying appreciable quantities of pyrite.

The writer regrets the paucity of data on which these statements are based and hopes that further experimentation will elaborate and verify or contradict their validity.

HEADS  
FLASK

DECANTOR  
FEEDER

ORE  
TUBE

TAILS  
CONTAINER

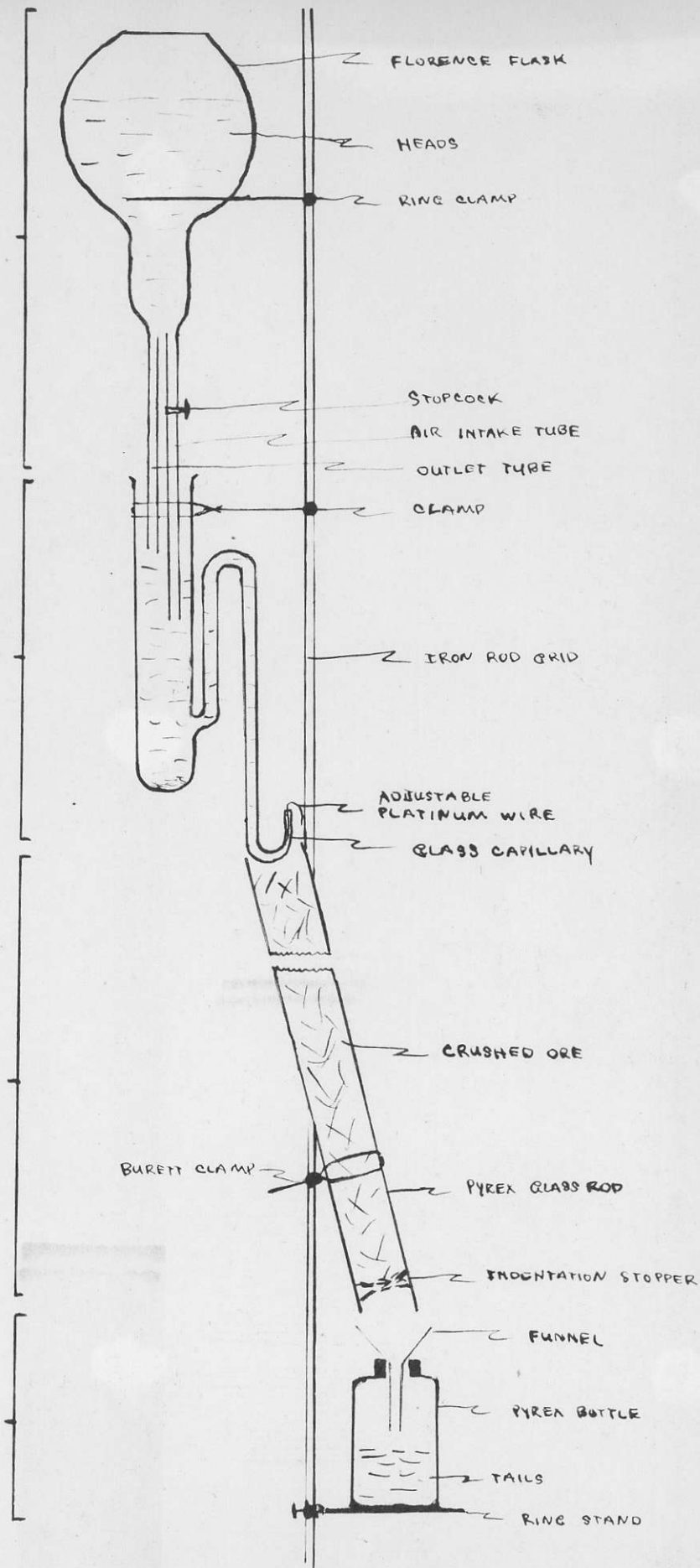
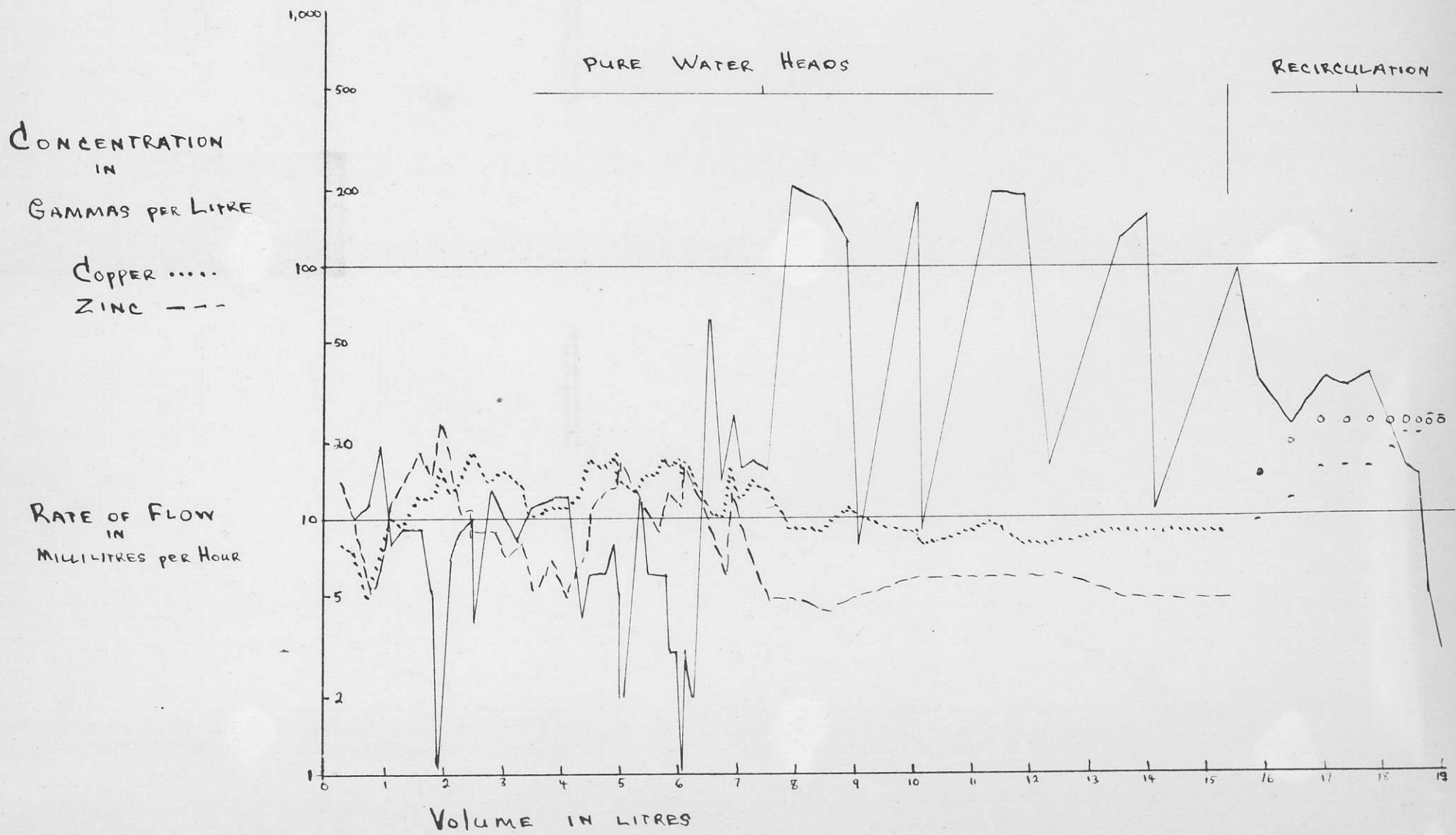


DIAGRAM OF A SET OF APPARATUS

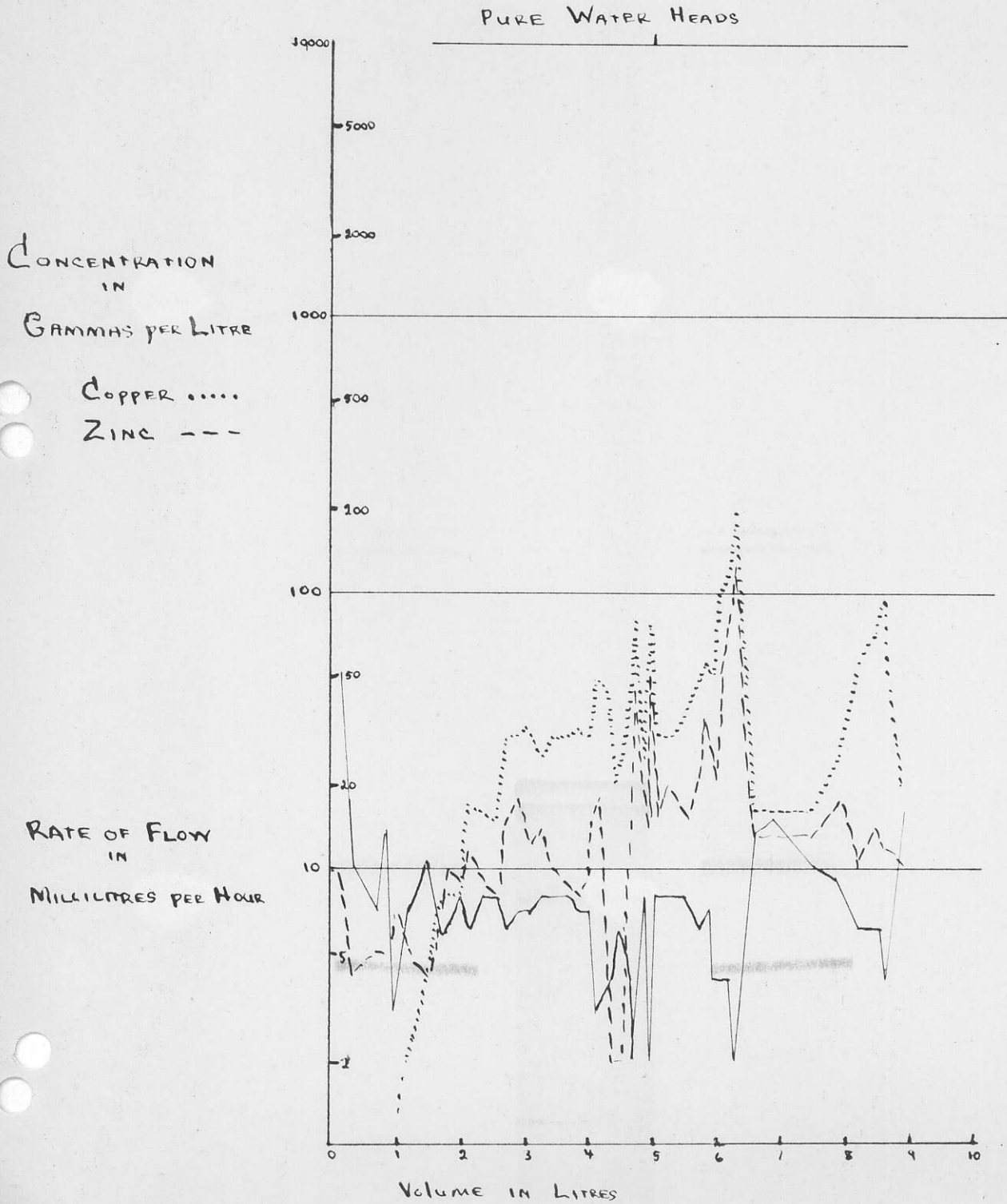
SET I PURE WATER ATTACK

ORE. FAIRVIEW



SET I PURE WATER ATTACK

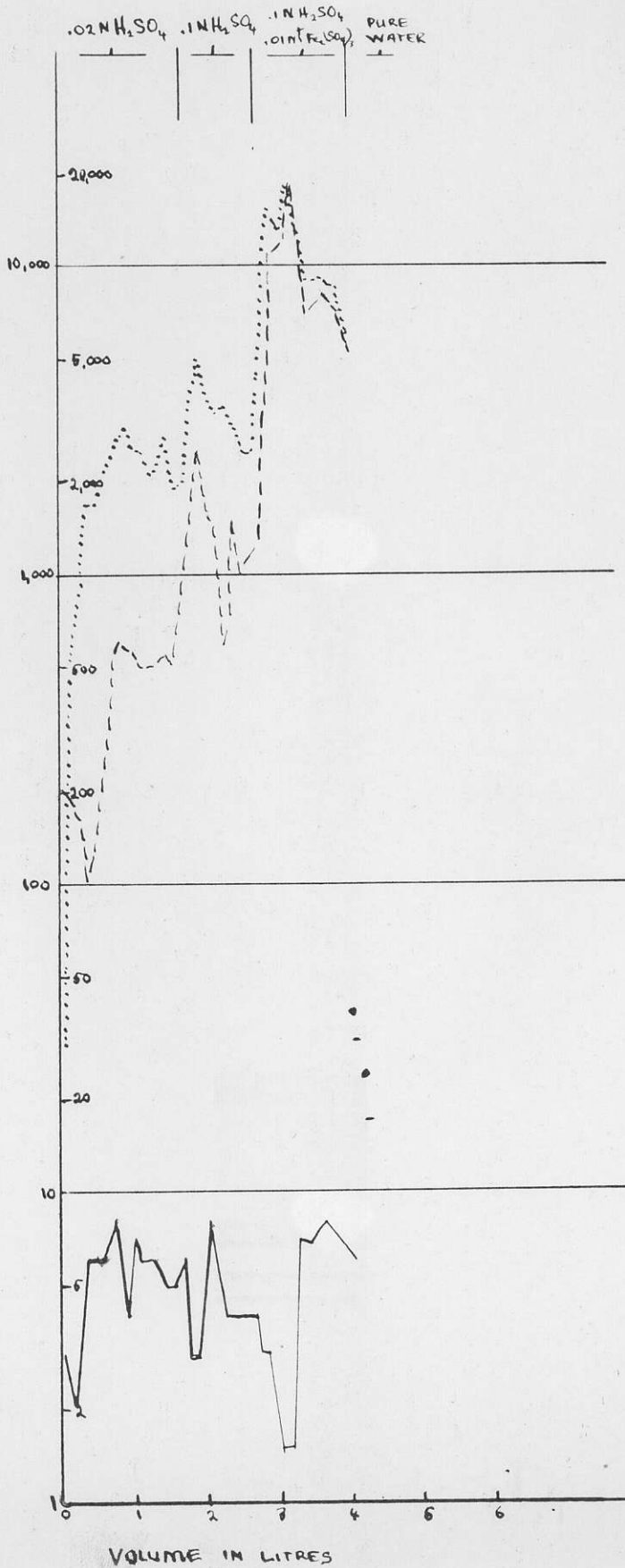
ORE HIGH GRADE CHALCOPYRITE



SET II — ACID ATTACK

ORE — FAIRVIEW

CONCENTRATION IN  
GAMMAS PER LITRE  
COPPER .....  
ZINC ----



RATE OF FLOW IN  
MILLILITRES PER HOUR

SET II ACID ATTACK

ORE HIGH GRADE CHALCOPYRITE

