



THE APPLICATION OF CYANOGEN

BROMIDE IN THE CYANIDATION

OF GOLD ORES.

BY

B. H. MOORE.

SOURCES OF INFORMATION.

In the original unpublished work submitted herewith, the experimental information has been obtained in the course of original investigations carried out in the Metallurgical Laboratory of the School of Mines of Western Australia, Kalgoorlie.

Specific reference has been made to published sources of information which have been made use of during this work.

A bibliography of bromocyanidation is also attached to the work on that subject.

A brief description of the methods of analysis adopted has been included in the form of an appendix.

B. H. Moore.

School of Mines of W. A.,
Kalgoorlie, 6th November, 1930.

INTRODUCTION.

In the investigation, of which this Thesis furnishes a detailed account, an endeavour has been made to determine the operating conditions under which cyanogen bromide may be successfully applied in the cyanidation of gold ores.

As an introduction and in order to show what has previously been done in this direction, a resume of the literature of bromocyanidation has been included, in which opinions regarding the chemical action of cyanogen bromide and the salient features of the practice of bromocyanidation during the period from 1895 until the process was superseded by the all-roasting and cyanidation process have been reviewed for the purpose of showing the uncertainty that existed, not only as regards correct operating conditions, but also as regards the chemical behaviour of cyanogen bromide in assisting in the solution of gold in cyanide solutions when dealing with refractory ores.

The experimental work described in this Thesis has been conducted for the purpose of ascertaining, if possible, the conditions necessary for successful bromocyanidation, the causes of failure, and a means by which the difficulties of treatment by this method may be overcome.

At the same time, no attempt has been made to establish definitely the actual chemical behaviour of cyanogen bromide, but extracts from the literature of the subject have been made in order to show the uncertainty that existed among advocates and opponents of the process regarding the chemical principles involved. In quoting from the literature of the subject, most of which was written and published in the early days of the process - 1895 to 1910 - opinions regarding the chemistry of bromocyanidation have been quoted as stated in the published papers by the adherents of the two different opinions regarding the action of cyanogen bromide.

Although at the present time it is considered that any substance which will absorb one electron from each atom of gold, thereby enabling the gold to pass into solution in the cyanide solution, is an oxidising agent, it must be remembered that thirty five years ago no such conception existed and that any substance which acted as an oxidising agent was considered to do so by supplying oxygen, either directly by its own decomposition or indirectly, by some series of reactions. Therefore the discussion during the period mentioned on the question of whether or not cyanogen bromide acted as an oxidising agent had for its object the demonstration of the possibility or impossibility of cyanogen bromide supplying the oxygen known to be necessary for solution of the gold, by some series of reactions taking place within the solution and in which cyanogen bromide played an important part. Those who favoured the hypothesis that cyanogen bromide acted as an oxidising agent endeavoured to show by means of equations, probable or improbable, that by a series of reactions taking place in the mixed cyanide and cyanogen bromide solution, the oxygen necessary for solution of the gold, as stated in Elsner's equation, was produced and that the increased solvent effect due to the use of cyanogen bromide was due to the fact that this oxygen was present in the solution in the nascent state. On the other hand, those who opposed the oxidising hypothesis endeavoured to show that oxygen could not be produced when cyanogen bromide was present in the solution and even went so far as to insist and endeavour to demonstrate that the presence of oxygen in the solution was a disadvantage.

At the time that these opinions were formulated physical chemistry was in its infancy and the broad use of the term oxidation which is today accepted had not come into vogue. Consequently, the early investigators who endeavoured to make the best use of the

chemical tools at their disposal should be judged rather by the standards of their own time than by those of the present day.

In the light of present day knowledge there is no need for speculation regarding the oxidising or non-oxidising action of cyanogen bromide in the cyanidation of gold ores, for it is now possible to affirm that it acts as an oxidising agent by absorbing one electron from each atom of gold and that it is immaterial whether or not oxygen is produced during the series of reactions that take place.

Hence, from the aspect of the application of the process to the cyanidation of refractory gold ores, it is important to determine whether cyanogen bromide can be successfully applied and, if so, whether that application can be made a commercial success. That this can be done has been shown by the experimental work described in this Thesis, but stress must be laid on the fact that this investigation has been carried out for the most part on the sulpho-telluride ores of Kalgoorlie. Other refractory ores have been tested similarly, although to a less extent, but the refractory arsenical ores of Wiluna have not been found to be amenable to this method of treatment. It has been shown that in the Kalgoorlie ores the gold is present in two distinct forms, viz., that which is free or in association with the pyrite and which is readily dissolved by plain cyanide solution, and that which is present in combination with tellurium and which is not readily soluble in plain cyanide solution but is soluble in the mixed cyanide and cyanogen bromide solution. In consequence of these two conditions of occurrence of the gold in these ores it has been found possible by flotation to segregate the two forms in two distinct products, one of which is amenable to treatment by cyanide solution alone and the other only to a mixed cyanide and cyanogen bromide solution.



THE APPLICATION OF CYANOGEN BROMIDE

IN

THE CYANIDATION OF GOLD ORES.

In the cyanidation of gold (and silver) ores, it has come to be accepted that Elsner's equation expresses the solvent action of dilute solutions of alkali or alkaline earth cyanides on gold (and silver)



According to this view, the solvent action of the cyanide solution is dependent on the presence of free oxygen in the solution in contact with the ore. This oxygen may be supplied, as is generally the case, from the atmosphere

- (a) in the form of oxygen dissolved by the solution from the air by simple contact with the air or by aeration of the solution during its flow along pipes and launders;
- (b) by agitation of the ore and solution with compressed air so that a continuous supply of oxygen is introduced during the period of contact of the ore with the cyanide solution;
- (c) by reason of the air which occupies the interstitial spaces between the particles of ore when at rest, as in the case of leaching by percolation;

or, by the introduction into the solution in contact with the ore or by mixing with the ore itself certain oxidising agents, the object of which is to supply, by their decomposition, a continuous supply of oxygen at the points of actual contact of the gold particles with the cyanide solution. To this class of substances belong sodium peroxide, potassium permanganate, potassium dichromate, bleaching powder, and certain other less common oxidising agents which have, in some cases, proved more or less efficient, but which have never received any extended use. Hence, in the cyanidation of ores which are capable of yielding an economic and commercial extraction by the solvent action of solutions of cyanides, it has been the usual practice to depend on the atmosphere for the necessary supply of oxygen.

In the treatment of many ores, particularly ores containing pyrite and marcasite, FeS_2 , arsenical pyrites, FeAsS , and tellurides and sulpho-tellurides of gold and silver, these methods of increasing the rate of solution of the gold have been but partially successful and as a result the extraction of the gold from the ore has not only been slow but has not been sufficiently great to render the treatment of these so-called refractory ores commercially successful. In order to overcome the difficulty of treatment of such ores numerous methods of accelerating the solvent action of the cyanide solution on the gold have been applied by making use of chemical substances which, while not of themselves solvents of gold, act as accelerators by virtue of the chemical reactions that take place between these substances and the cyanides. Of these accelerators, those which have received most application and have been used to the greatest extent have been the halides of cyanogen, cyanogen chloride, CNCl , cyanogen bromide, CNBr , and cyanogen iodide, CNI , the use of the second of which has in certain cases been shown to result in a much increased rate of solution of the gold and percentage extraction in a given time. Although the application of cyanogen chloride and iodide has been suggested, it has been found that, both in the laboratory and in the treatment plant, there are many difficulties attending their use, caused partly by the properties of these compounds rendering them unsuitable for this purpose and by the expense of producing these reagents on a commercial scale. Consequently, most attention has been paid to the application of cyanogen bromide to this purpose, this compound being cheaply producible on the scale necessary for its commercial application and being relatively stable under the conditions of treatment usually obtaining in a gold or silver cyanide plant. The exact action of these cyanogen halides in

promoting the dissolution of the gold has not been conclusively proved, there being two main hypotheses, viz.,

- (i) that the cyanogen halides take the place of the oxygen which is considered necessary if Elsner's equation is held to express correctly the solvent action of cyanide solutions under ordinary conditions of treatment; according to this view, the presence of oxygen during treatment is unnecessary and, in fact, deleterious when cyanogen halides are used;
- (ii) that the action of the cyanogen halides is in reality an oxidising action brought about by the production of "nascent" oxygen by the decomposition of the cyanogen halides by hydrolysis or by hydrolysis in conjunction with a decomposition taking place between the alkali cyanide and the cyanogen halide; according to this view the oxygen is produced in an active state at the points where its presence is most necessary, viz., the points of contact of the solution with the particles of ore.

Arguments, apparently quite justifiable, have been adduced by each school of thought to prove the correctness of its particular view, but the evidence put forward has been comparatively meagre and it is difficult to come to a definite conclusion as to which hypothesis is the more nearly correct. A search of the literature of the process has brought to light a considerable amount of information but the chemical action of the cyanogen bromide as an accelerator of solution of gold by cyanides still remains undecided, while the details of the practical application of the process that have been published are very scanty and not particularly enlightening. Unfortunately, at Kalgoorlie, where the process has been most extensively employed, a policy of secrecy appears to have been adopted by the officers in charge of plants using the process, so that only the most meagre information is available regarding the practice on the field where most information should have been available.

Of the various attempts to make use of the solvent action of the halogens in conjunction with alkali or alkaline earth cyanides, the only process for which any measure of success can be claimed is that of Sulman and Teed (W. A. Patent 601 of 1894) in which cyanogen bromide and potassium cyanide constituted the solvent solution. Previous attempts had been made to use cyanogen bromide as a solvent for gold but these do not call for special notice, since cyanogen bromide alone is not a solvent for gold. It remained for Sulman and Teed to demonstrate that a solution containing potassium cyanide and cyanogen bromide had a much more rapid solvent action on the gold contained in ores containing metallic sulphides and tellurides and also in ores containing no auriferous refractory minerals than had a solution of cyanide alone.

Although cyanogen bromide was at one time in use on a comparatively large scale in the treatment of the sulpho-telluride ores of Kalgoorlie, and with considerable success, the process has during the last few years fallen into disuse, or rather, the mills which formerly used the process have now all ceased operations or have remodelled their treatment plants and have adopted in lieu of the "bromocyanide" process a dry-crushing, all-roasting process in which plain cyanide solution is used. In the early days of the Kalgoorlie field, roasting of these ores apparently presented considerable difficulty, but, as these difficulties have since been overcome, the tendency has been more and more towards the use of the all-roasting process in preference to the "bromocyanide" process. Adherents of the all-roasting process claim that it gives higher recoveries than the "bromocyanide" process but to the writer it seems doubtful whether this is so or whether the cost of treatment by the former is less than by the latter process. The "bromocyanide"

RESUME
OF
THE LITERATURE OF BROMOCYANIDATION.

During the course of the investigation into the application of cyanogen bromide to the cyanidation of the sulpho-telluride ores of Kalgoorlie, of which this Thesis constitutes a detailed account, it was necessary to make a search of the metallurgical literature of the subject in order to ascertain the extent to which treatment conditions had been determined and the state of knowledge of the chemical principles of the process.

Although the determination of the treatment conditions necessary for successful application of cyanogen bromide has been the primary object of this investigation and therefore constitutes the main portion of this Thesis, a review of the literature of the subject has also been included for the purpose of showing the extent of the knowledge of the process and its principles at the time it was in actual operation at Kalgoorlie.

- Consequently, the Thesis falls into two distinct sections
- (a) A review of the literature of the subject,
 - (b) An account of the metallurgical investigation conducted to determine operating conditions necessary for success, and the conclusions to be drawn therefrom.

As Section (a) has been introduced purely for the purpose of showing the state of knowledge of the process, it has been considered to be of secondary importance in its relationship to the major portion of the work, viz., that included in Section (b).

In this investigation, determination of treatment conditions necessary for success has been the primary object and therefore no attempt has been made to investigate the chemistry of the process. Consequently, the existing literature of the subject, which, having been published nearly thirty five years ago, naturally does not take cognisance of modern conceptions of physical chemistry, has not been critically examined.

process has the advantage that it is entirely a wet treatment process in which no dust is produced, crushing and grinding are cheaper and the plant necessary is smaller and less complicated on account of the elimination of roasting. In the roasting process the whole of the ore is subjected to this operation, whereas the ore contains only 5 to 8 per cent. of pyrite, the only mineral requiring roasting before cyanidation, and therefore enormous quantities of expensive fuel are used in raising the remainder of the ore to the temperature necessary for oxidation of the sulphide mineral. Apart from the difference in the method of crushing, the main difference in the method of treatment is in the use of cyanogen bromide instead of the roasting operation and therefore, if the two processes yield the same extraction the important factors in comparing the two processes are the cost of cyanogen bromide as compared with the cost of roasting. The former costs up to two shillings and six pence per ton of ore, whereas it is extremely doubtful whether the cost of roasting has ever been reduced to this amount. Therefore, other things being equal, the "bromocyanide" process has the advantage of requiring a less expensive plant, since roasting is entirely avoided, and therefore the capital expenditure on plant is much smaller in the case of the "bromocyanide" process. In addition, the dry treatment process produces a large quantity of dust which is objectionable, not only from a hygienic point of view, but also on account of the increased wear and tear on the machinery of the treatment plant. Further, for the dry treatment process, the percentage of moisture in the ore supplied to the dry-crushing mills must be kept as low as possible to avoid clogging of mill screens, and this in turn limits the use of water for dust prevention during mining operations; on the other hand, for a wet treatment process, such as the "bromocyanide" process, no such restriction of the use of water underground is necessary. Hence it is apparent that if the wet treatment process can compete with the dry treatment process as regards percentage recovery and costs, all other considerations will be in favour of the former process.

RESUME OF THE LITERATURE OF BROMOCYANIDATION.

H. L. Sulman in 1895 presented a paper before the Institution of Mining and Metallurgy on the Sulman-Teed process in which he seeks to explain the accelerating action of cyanogen bromide and also gives examples of the commercial application of the process to the treatment of sulphide ores from which, hitherto, satisfactorily high percentage extractions had been unattainable by ordinary methods of cyanide treatment. At that time the cyanide process had not long been introduced and although the MacArthur-Forrest patent specifications were very complete, comparatively little information was available regarding the applicability of this method of treatment to complex ores, i.e., to ores containing metallic sulphides and similar minerals. At that time it was considered that the MacArthur-Forrest process was not applicable to rich pyritic ores and concentrates, whereas at the present time the process has been so developed that the number of classes of ore which can not be successfully treated by direct cyanidation is very small. It is, of course, understood that the cyanide process can not successfully supplant the amalgamation process for the recovery of "coarse" gold, the solution of which by cyanide solutions is too slow to be economically practicable.

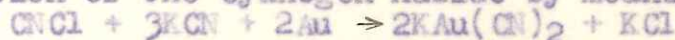
According to Sulman, the treatment of sulphide ores by cyanidation, using atmospheric oxygen as the source of supply of the necessary oxygen possesses two distinct and important disadvantages, viz.,

- (i) during treatment, oxidation of iron and other base metal sulphides takes place and the products of this oxidation

rapidly destroy simple cyanides;

- (ii) potassium hydroxide is produced in the dissolving reaction, which reacts with sulphides of iron, copper, arsenic, antimony, etc., to form alkaline sulphides which are powerful cyanicides.

Sulman claims that the Sulman-Teed process, using cyanogen bromide in conjunction with potassium cyanide gives rapid and successful extractions from refractory ores such as those containing sulphides of copper, arsenic, and antimony, to which the ordinary cyanide process is inapplicable. He ascribes the results obtained by the use of the Sulman-Teed process mainly to an enormously increased solvent action because of the presence of "potential" or "available" cyanogen which will combine with gold to form the aurous cyanide necessary for the formation of potassium aurocyanide and the avoidance of the production of potassium hydroxide which assists in the production of cyanicides by forming soluble base metal hydroxides and alkaline sulphides, all of which are rapid destroyers of cyanide. (Here Sulman evidently refers particularly to the formation of ferrous hydroxide which reacts with potassium cyanide, forming potassium ferrocyanide, i.e., he apparently uses "soluble" to refer to the fact that these base metal hydroxides are soluble in solutions of potassium cyanide.) He asserts that, if chlorine or other halogen is used in conjunction with cyanide, the solvent reaction is expressed by the equation $4KCN + 2Au + Cl_2 \Rightarrow 2KAu(CN)_2 + 2KCl$, in which case the halogen does not act as an oxidising agent, no hydrolysis takes place, and no extraneous addition is necessary. If, however, the halogen is used in the form of a cyanogen halide, the whole of the cyanogen, both of the potassium cyanide and of the cyanogen halide, goes to the production of soluble potassium aurocyanide, and that for the same quantity of gold converted to the soluble form, the expenditure of halogen is only half of that used in the former case. He expresses the action of the cyanogen halide by means of the equation



Similar reactions, of course, are claimed for the other halides of cyanogen, such as cyanogen bromide, CNBr, and cyanogen iodide, CNI. Sulman states, as the result of experiment, that the rate of solution of particles of free gold in an equally fine state of subdivision is over one hundred times as rapid with cyanogen chloride and potassium cyanide as with potassium cyanide alone. He goes on to say that in the application of the ordinary cyanide process it is essential that a supply of oxygen be provided, either in the form of dissolved oxygen or in the form of some oxidising agent which, however, tends to oxidise base metal sulphides, producing compounds which decompose cyanide and so impair the efficiency of the cyanide solution. Among the compounds formed in this way are soluble alkaline sulphides, the deleterious action of which was recognised by MacArthur who, with Ellis, patented the use of lead salts for the purpose of rendering these cyanicides innocuous by precipitating them as lead sulphide, which is itself not harmful. Cyanicides are thus generated at the point where solution of the gold takes place, and, as many of these cyanicides are readily oxidisable, they combine with the oxygen necessary for dissolution of the gold. Sulman states that simple chlorination or bromination of cyanide solution will produce the accelerator cyanogen chloride or cyanogen bromide



but excess of KCN must be present to give the proportion required by



The addition of the pure cyanogen halide to a cyanide solution gives a better solvent for this reason than is obtained by adding the halogen to the ordinary cyanide solution. While specifically stating that cyanogen halides are not, per se, solvents of gold, Sulman declares that if cyanogen bromide is added in definite proportion to a solution of potassium cyanide, no change takes place in the nature of the compounds present and the solution remains stable indefinitely.

This does not appear to be the case with working solutions as ordinarily prepared, since a mixed solution of potassium cyanide and cyanogen bromide loses strength, both in cyanide and in cyanogen bromide on standing either in closed or in

open vessels or when exposed to the light or when kept in the dark.

Cyanogen chloride and cyanogen iodide are both unsuitable for practical use, the former on account of its physical properties, the most important of which is its low boiling point ($16^{\circ}\text{C}.$) and the latter on account of the high cost of its production, although it was ~~made~~ used of some years ago in conjunction with calcium cyanamide by Clancy. In addition, cyanogen chloride, which on account of the cheapness of the chlorine necessary for its production, is the cheapest of the cyanogen halides to produce, is much less efficient as an accelerator than cyanogen bromide; in fact, some experiments have shown that solutions of cyanogen chloride and potassium cyanide under certain conditions are less efficient solvents of gold than potassium cyanide alone (Stevens and Blackett, Trans. Inst. Min. & Met., 1919). Consequently, cyanogen bromide whose use is not attended with any of the difficulties encountered when using the other halides, has been the compound generally used.

At the time of the presentation of Sulman's paper it was apparently proposed to use the improved method of solution with potassium cyanide and cyanogen bromide in the treatment of auriferous material by percolation, since at that time satisfactory methods had not been devised for the cyanidation of slime which, when produced in moderate quantity during the crushing of the ore was mixed with the sand for leaching, and when produced in quantities too great for this method of treatment, was separated from the sand and reserved for subsequent treatment. In the treatment of the sand or sand and slime by percolation, the plant proposed was similar to that used in the ordinary cyanide process and cyanogen bromide was to be added to the cyanide solution storage tank in quantity not exceeding one molecule of cyanogen bromide to three molecules of potassium cyanide, as required by Sulman's equation, or, practically, one part of cyanogen bromide to two parts of potassium cyanide, by weight. This proportion was stated to be a maximum because ~~the~~ in the treatment process it is not necessary nor desirable to use up the whole of the potassium cyanide in the dissolving reaction.

It was stated that there was a maximum strength of leaching solution and that if a concentration of 0.6 per cent. KCN and 0.3 per cent. CNBr, which is never necessary in practice, is exceeded, there is a tendency towards decomposition of the cyanide and cyanogen bromide with the formation of inactive, brown paracyanogen, $(\text{CN})_3$



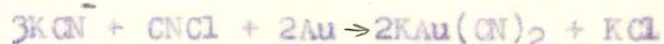
Apparently, the more dilute the liquor, the greater its stability.

In quoted cases of laboratory application of the process to the treatment of complex ores and pyritic concentrates, twenty four hours' treatment was usually sufficient and in every case forty eight hours' treatment showed the maximum extraction possible. Sulman quotes the results of a number of laboratory tests on ores and concentrates, as follows :-

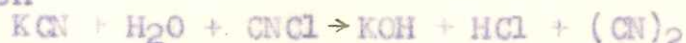
Ore	KCN %	CNBr %	Time of treatment hours	Method of treatment	Extraction per cent.
Tailings	0.2	0.12	over night	Percolation	81
Pyritic Concentrate	0.5	0.25	15	"	91
Pyritic Concentrate	0.5	0.25	9	"	96
Arsenical Pyrites	0.3	0.12	0.5	Agitation	74
Coolgardie Ore	0.3	0.125	15	Percolation	84.1
Pyritic Ore	0.2	0.08	12	"	96
Coolgardie Ore	0.3	0.18	15	"	96
Pyritic Tailings	0.45	0.2	24	"	90.3
Coarse Tailings	0.1	0.05	19	"	70
contg. FeS ₂ & PbS					
Copper-antimony Concentrate	0.5	0.25	15	"	95.7

Sulman and Teed make only one reference to limitation of the use of alkali when, in a brief description of their method of treatment, they state that soluble cyanicides are removed by a water wash and basic salts by treatment with alkali, before cyanide treatment, and that they avoid the use of excess of alkali which retards leaching. It will be shown later that the limitation of the quantity of alkali, either when giving a preliminary wash or during the treatment with cyanide and cyanogen bromide is one of the most important features of the process on account of the rapid decomposing effect of alkalies on cyanogen bromide.

In the discussion which ensued on Sulman's papers, the principal point at issue seems to have been whether the action of cyanogen bromide could or could not be considered to be an oxidising action. Sulman and Teed insisted that the action of cyanogen bromide was not an oxidising action, and, in fact, Sulman recommended that during the leaching operation air should be excluded, so far as possible, by covering the ore so as to prevent currents of air coming into contact with the ore. Bertram Blount declared that the action of cyanogen bromide is an oxidising action and that the function of the bromine is "to provide a negative element to combine with the potassium which would otherwise go free". Hence, he says, it acts in the same way as oxygen in the ordinary process. F. L. Teed, joint inventor with Sulman of the process, in upholding the non-oxidising action hypothesis, gave as the action of the cyanogen halides



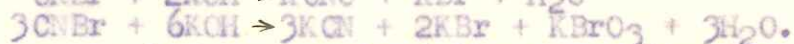
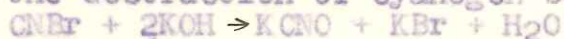
in which oxygen plays no part; in contrast to this reaction he put forward an equation



in possible explanation of the oxidising action or hydrolysis hypothesis which he declared to be impossible on account of the production of equivalent quantities of potassium hydroxide and hydrochloric acid together.

Cyanogen, however, is recognised as a non-solvent of gold, so that this reaction would be of no material benefit unless the cyanogen were capable of combining directly with gold and potassium to form the soluble potassium aurocyanide, $\text{KAu}(\text{CN})_2$.

Teed also explained the harmful effect of potassium hydroxide on the cyanogen bromide by means of the following equations showing the destruction of cyanogen bromide



Teed therefore seems to have recognised the necessity for avoiding the addition of an excess of alkali.

In Appendix 7 to the Report of the Department of Mines of Western Australia for 1895, Inspector of Mines Frank Reed, in submitting a paper on the process by H. L. Sulman, states that "the process is in use at the Rand mines, in Arizona, Hungary, Canada, and elsewhere and is doing excellent and rapid work on ores which the older cyanide process has signally failed to extract, and it is being brought into use at Day Dawn Mine and at Coelgardie". In this paper Sulman claims as the chief advantages of the process its simplicity, shortness of the extraction period (economy in time permitting of reduction of plant capacity) and reduced cost of treatment, easier recovery of gold from solution and the applicability of the process to refractory ores, concentrates and tailings hitherto intractable to plain cyanide. No further information is given in this paper except the method of application and the results at the Day Dawn Mine where leaching with the mixed solution was practised. The following are the essential facts in connection with the application of the process at this mine :- In 8 to 12 hours the whole of the accessible gold (i.e., not imprisoned in the quartz) was extracted, the consumption of reagents being KCN, less than 0.25 pound and CNBr, less than 0.125 pound per ton of tailings, while the cost of the materials consumed was less than one shilling per ton of ore. Two solutions were used for leaching, a strong solution containing 0.1 per cent. KCN and 0.025 per cent. CNBr, and a weak solution containing 0.04 to 0.05 per cent. KCN. The weak solution was used to displace the strong solution and was itself displaced by the application of a water wash. Three hundred tons of tailings, assaying 4 dwt. 7 gr. gold per ton, were treated in one week, producing a 12 grain residue after 15 hours' leaching, at a working cost (including depreciation and interest on plant) of three shillings and tenpence per ton of ore.

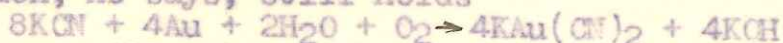
It was unfortunate that the first application of the process in Australia should have been made on an ore for which the special solvent was totally unnecessary, this ore being capable of yielding very high percentage recoveries by amalgamation and direct cyanidation with cyanide alone, of the residue after amalgamation. This was a test of the process under ideal conditions instead of on those classes of ore for which it was claimed by the inventors that the process was specially suitable. No comparison of the results of treatment with plain cyanide and with cyanide and cyanogen bromide is given so that it is not possible to form an idea whether the process was capable of performing the work claimed for it by its inventors on refractory ores, i.e., ores difficult or impossible of treatment by ordinary methods of cyanidation. The process was later discarded at this mine and plain cyanidation of the residue after amalgamation was installed, which process gave excellent results.

A further paper presented by Sulman before the Chemical and Metallurgical Society of South Africa on May 11th, 1895, and published in the Proceedings of that Society, Vol. I, 1894-1897, entitled "Notes on the Behaviour of the Haloid Elements in Conjunction with the Cyanide Process" brings forward no fresh information of any consequence and appears to have been for the most part a repetition of his previous paper before the Institution of Mining and Metallurgy. He again stresses the facts that when using cyanogen bromide, oxygen is unnecessary and that the deleterious effects of the production of potassium hydroxide are avoided. He advocates the covering of leaching tanks to exclude currents of air and also states that the consumption of cyanogen bromide is diminished by adding that reagent in instalments. The paper is only of value on account of the discussion it evoked, when the chemistry of the process was gone into at considerable length by some of the leading cyanide operators in South Africa.

Schlunde strongly opposed Sulman and Teed's statement that cyanogen bromide does not act as an oxidising agent and in declaring his belief that cyanogen bromide acts as an oxidising agent puts forward his view that it takes away one atom of hydrogen from water and leaves free hydroxyl radicals to form KCNO, potassium cyanate. This decomposition, he states, is more rapid in the presence of alkalis

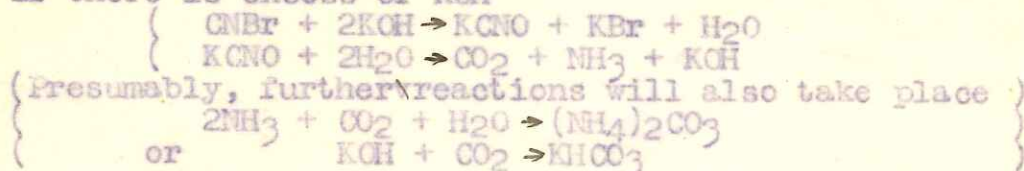


Elser's equation, he says, still holds

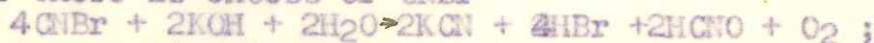


but the KOH formed will act on CNBr

(a) if there is excess of KOH



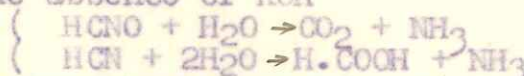
(b) if there is excess of CNBr



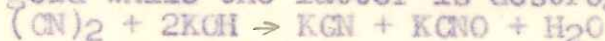
this reaction is momentary because



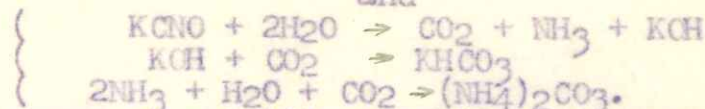
In the absence of KOH



In both cases cyanogen compounds are destroyed and in the second case free oxygen is produced. If free cyanogen is formed in the solution, it will not directly act on gold but in the presence of alkali will form potassium cyanide and cyanate, the former acting as a solvent of gold while the latter is destroyed by hydrolysis



and



In the presence of metallic sulphides, decomposition of the cyanide compounds would be greater, owing to the nascent oxygen and hydrobromic acid developed in the reaction. Further, the more oxidisable metals would be attacked in preference to the gold. Schlunde therefore comes to the following conclusions -

- (i) cyanogen bromide is rapidly decomposed and has no direct action on gold;
- (ii) cyanogen bromide cannot make a bromination or a cyanation but an excess of it will generate nascent oxygen;
- (iii) the potassium cyanide is converted into cyanate and further oxidised, decomposed, and destroyed.

Fleming quoted the results of some experiments on the process which showed a smaller extraction of gold and a larger loss of cyanide than by the ordinary process.

Buchanan compared the results obtained by the Sulman-Teed and the MacArthur-Forrest processes on concentrates assaying 22 dwt. gold per ton with a twelve-hour period of contact, both tests being carried out in an atmosphere of nitrogen. The results were as follows :-

	Sulman-Teed	MacArthur-Forrest
Solution, (KCN, per cent.	0.22	0.27
(CNBr, per cent.	0.05	-
Extraction, per cent.	65	nil
KCN Consumption, lb. per ton	2.5	nil

He raises the question " does or does not the cyanogen bromide in contact with water in a solution undergoing active chemical change, form hydrocyanic acid, hydrobromic acid and free oxygen which then takes part in the solution of the gold".

Buchanan's experiments only prove that in the ordinary process the complete absence of oxygen prevents solution of the gold, but they do not indicate whether solution in the presence of cyanogen bromide is due solely to the action of cyanogen bromide and potassium cyanide or to the action of oxygen produced by some reactions between the cyanide, the bromide and water. This suggests the possibility of utilising the oxygen-absorbing power of pyrogallic acid to determine whether any oxygen is produced when oxygen-free solutions of potassium cyanide and cyanogen bromide are mixed and allowed to stand in an atmosphere of nitrogen.

Clennell, in advocating the theory of the oxidising action of cyanogen bromide, discussed in detail the chemistry of the process and gave the results of experiments on the behaviour of cyanogen bromide under various conditions. In discussing the nature of the reaction, Clennell described experiments which showed that

- (a) a dilute solution of potassium cyanide slowly evolves hydrocyanic acid
- (b) a dilute solution of cyanogen bromide evolves no hydrocyanic acid
- (c) a mixture of the dilute solutions of potassium cyanide and cyanogen bromide rapidly evolves hydrocyanic acid.

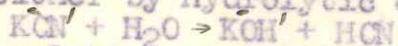
The evolution of hydrocyanic acid was detected by exposing a solution of silver nitrate on a watch glass over beakers containing the solutions and observing whether a white precipitate was formed on the watch glass. In support of his argument that the accelerating action of cyanogen bromide is due to its behaviour as an oxidising agent he says "hydrocyanic acid can not be produced without hydrogen the only source of which is the water of the solution; removal of hydrogen from water leaves either free oxygen or hydrogen peroxide".

The writer, in an endeavour to confirm the results of Clennell's experiments, carried out similar qualitative tests on

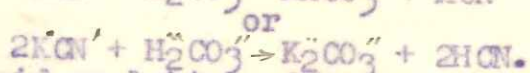
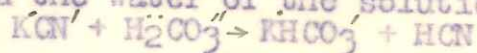
- (a) potassium cyanide solution containing 0.148 per cent. KCN,
- (b) cyanogen bromide solution containing 0.05 per cent. CNBr,
- (c) mixed solution containing 0.148 per cent. KCN and 0.05 per cent. CNBr.

In the case of solution (a) turbidity developed slowly in the silver nitrate solution which became quite dense in 30 minutes; in the case of solution (b) a slight turbidity developed in the silver nitrate solution in 30 minutes; in the case of solution (c) dense turbidity developed in the silver nitrate solution at once. These experiments show that the cause of the turbidity of the solution of silver nitrate develops rapidly in the case of a mixed solution, much more slowly in the case of a plain cyanide solution and extremely slowly in the case of a solution of cyanogen bromide. This does not, however, prove that the turbidity is due, as Clennell suggested, to the liberation of hydrocyanic acid, for it might be due to the liberation of hydrobromic acid or of both hydrocyanic and hydrobromic acids. The chemical explanation of the different behaviour of these three solutions may possibly be as follows :-

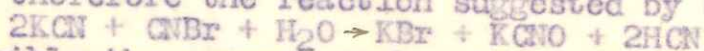
A dilute solution of potassium cyanide slowly evolves hydrocyanic acid, either by hydrolytic dissociation



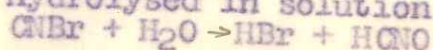
in which case the evolution of hydrocyanic acid would be very slight, or by the action of carbonic acid, i.e., the action of atmospheric carbon dioxide and the water of the solution



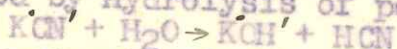
The rapid evolution of hydrocyanic acid when the solutions of potassium cyanide and cyanogen bromide are mixed can only be explained by assuming that a reaction takes place between the two compounds in solution and therefore the reaction suggested by Clennell



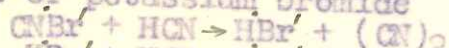
is quite possibly the correct explanation of the more rapid evolution of hydrocyanic acid in this case. Schlunde, however, says that cyanogen bromide is hydrolysed in solution



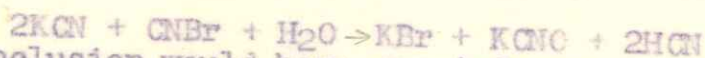
but, as, in Clennell's tests, a solution of cyanogen bromide alone gave a negative result, it is not possible to ascribe the result of the mixed solution test to the evolution of this gas unless the presence of potassium cyanide enormously increases this hydrolysis. The only way in which, apparently, hydrobromic acid could possibly be evolved from the mixed solution would be by the action of hydrocyanic acid produced by hydrolysis of potassium cyanide



on cyanogen bromide or potassium bromide



but, as hydrobromic acid is a very strong acid and hydrocyanic acid an extremely weak one, it is highly improbable that these reactions could take place. Free cyanogen has no action on silver nitrate and therefore the rapid turbidity produced in the solution of silver nitrate exposed to the action of the solutions in Clennell's tests could only be produced by the action of hydrobromic or hydrocyanic acid. From what has been said above, the evolution of hydrobromic acid is apparently impossible, so that in all probability evolution of hydrocyanic acid was the cause of the turbidity produced in these tests. Hence it follows that Clennell's explanation of the behaviour of a mixed solution of potassium cyanide and cyanogen bromide is a feasible one



although his conclusion would have carried more weight had he shown that the white precipitate produced in the silver nitrate solution was silver cyanide.

Clennell then proceeded to give the results of experiments on the behaviour of mixed solutions of potassium cyanide and cyanogen bromide, a resume of which is here given, together with the conclusions he arrived at as a result thereof.

1. In a mixed solution of potassium cyanide and cyanogen bromide a large part of the potassium cyanide is converted into hydrocyanic acid in a very short time. A solution containing 0.17 per cent. KCN and 0.17 per cent. CNBr after exposure to the air in an open vessel showed 0.065 per cent. KCN and 0.100 per cent. as HCN while 0.005 per cent. KCN was lost. A solution containing 0.21 per cent. KCN and 0.105 per cent. CNBr after being kept in a stoppered bottle in the dark for four and a half hours showed 0.145 per cent. KCN and HCN equivalent to 0.075 per cent. KCN.
2. When the solutions are kept in closed bottles the amount of cyanogen present as KCN + HCN remains practically constant. This was proved by adding excess of alkali to the solution before testing with silver nitrate so that HCN was converted to KCN and was estimated as an equivalent quantity of KCN. This addition of alkali does not convert the cyanogen of the cyanogen bromide into KCN.
3. The amount of CNBr diminishes rapidly both in open and closed vessels, whether exposed to light or in the dark. In an open jar a mixed solution containing 0.17 per cent. KCN and 0.17 per cent. CNBr showed immediately after mixing 0.152 per cent. CNBr; after two hours 0.071 per cent. CNBr; and after twenty hours 0.010 per cent. CNBr. In closed jars a solution containing 0.21 per cent. KCN and 0.105 per cent. CNBr showed after four and a half hours in the dark 0.016 per cent. CNBr and after four and a half hours in the light 0.013 per cent. CNBr.
4. Addition of excess of caustic alkali immediately destroys all CNBr whether KCN is present or not. When caustic alkali is added to a pure solution of CNBr, titration with silver nitrate at once gave a precipitate not soluble in excess of the CNBr solution and therefore no alkaline cyanide is liberated. When caustic alkali is added to a freshly prepared mixture of KCN and CNBr, the strength of the KCN, as indicated by silver nitrate, is the same as before addition of alkali and therefore the cyanogen of the CNBr does not appear as alkali cyanide.

In treatment tests by the writer in 1927, when lime was not added before filtration of the charge after treatment, the free

- KCN as determined by titration with silver nitrate, was less than after addition of lime, the difference being due either to the slight excess of KCN in the CNBr solution or to the neutralisation of HCN by the lime. This action of caustic alkali on the CNBr in a mixed solution of KCN and CNBr is one of the most important points in the process of treatment and the best results are obtained by so regulating the addition of alkali to the ore that the solution during treatment is acid or neutral, or, at the worst, shows only a trace of protective alkali. When treatment is carried out with a mixed KCN and CNBr solution which shows the usual protective alkali employed in the ordinary process with cyanide alone the rate of dissolution of the gold is materially diminished and is but little greater than in the ordinary cyanide process, while practically no increase in the extraction results from treatment with KCN + CNBr solution under these conditions. Therefore, it is essential for successful treatment that the addition of lime to the ore charge for treatment must be very carefully regulated so that the solution shows, at most, only a trace of protective alkali.
5. When the proportion of CNBr in the mixture was diminished, decomposition of KCN was not so rapid but the loss of CNBr was more rapid. Two hours' exposure to light of mixed solutions of the following composition gave the results shown below :-

	(a)	(b)
Mixed solution	(KCN, 1 part CNBr, 1 part	KCN, 2 parts CNBr, 1 part
Decomposition of total KCN present	62 - 53%	21.5 - 26%
Consumption of CNBr	58.2 - 61%	72.4 - 67.6%

Solution (b) contains the proportions recommended by Sulman.

6. In the dark the rate of decomposition was retarded. A mixed solution containing 0.21 per cent. KCN and 0.105 per cent. CNBr after four and a half hours' exposure showed the following concentrations of KCN and CNBr under the conditions stated :-
- Open vessel, exposed to light - 0.145% KCN, 0.01% CNBr
 Open vessel, in the dark - 0.17% KCN, 0.021% CNBr
 Closed vessel, exposed to light - 0.14% KCN, 0.013% CNBr
 Closed vessel, in the dark - 0.145% KCN, 0.016% CNBr.
- It might have been expected that the decomposition of both KCN and CNBr would have been least in a closed vessel kept in the dark, whereas the best result was obtained in an open vessel kept in the dark. Experiments by the writer with mixed solutions in open and closed vessels exposed to light showed that the decomposition of both KCN and CNBr was continuous and rapid under these conditions which approximate most nearly to the conditions obtaining in mill treatment. The results of these tests are shown in the following tables :-

Decomposition of KCN and CNBr

Time hours	Open Vessel			Closed Vessel		
	KCN %	HCN %	CNBr %	KCN %	HCN %	CNBr %
0	0.123	0.005	0.044	0.123	0.005	0.044
0.5	0.105	0.012	0.029	0.102	0.014	0.029
1.0	0.097	0.013	0.024	0.099	0.0145	0.024
2.0	0.0855	0.014	0.014	0.0905	0.012	0.015
3.0	0.082	0.012	0.010	0.084	0.013	0.009
3.5	0.082	0.015	0.0016	0.080	0.024	0.002
6.0			0.0016			0.0018

Expressing the percentages of HCN as equivalent percentages of KCN, the results show that the sum of the percentages expressed as KCN is not constant, so that there is an appreciable loss of cyanogen. The results in this form are shown below.

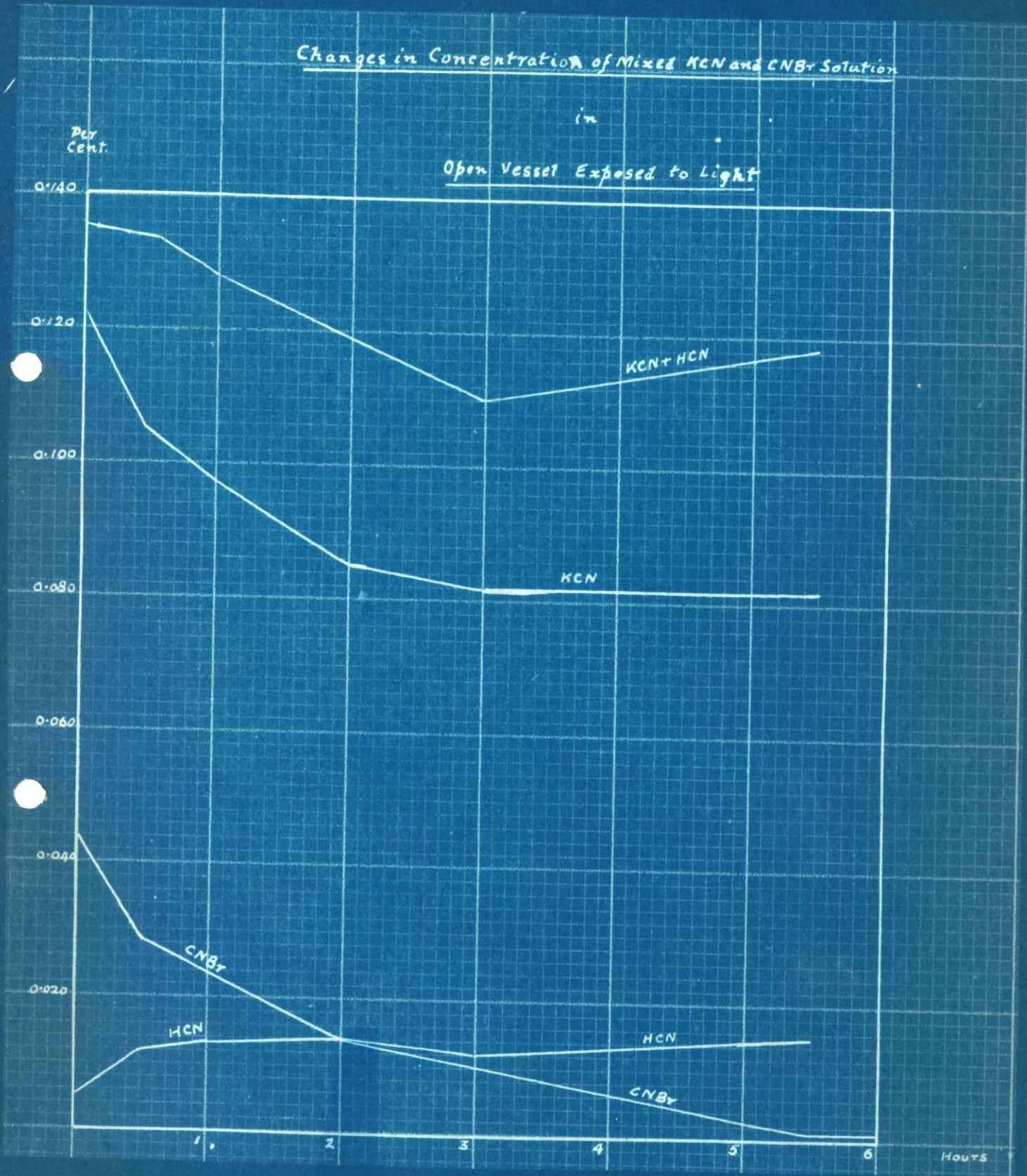
Time hours	Open Vessel			Closed Vessel		
	KCN %	HCN exp. as KCN %	Total %	KCN %	HCN exp. as KCN %	Total %
0	0.123	0.012	0.135	0.123	0.012	0.135
0.5	0.105	0.029	0.134	0.102	0.033	0.135
1.0	0.097	0.031	0.128	0.099	0.035	0.134
2.0	0.0855	0.034	0.1195	0.0905	0.028	0.1185
3.0	0.082	0.028	0.110	0.084	0.031	0.115
5.5	0.082	0.036	0.118	0.080	0.058	0.138

It appears, therefore, that, under these conditions, the total KCN + HCN remains practically constant up to one hour after mixing, but that after that time the loss becomes very marked. The changes in concentration of KCN, HCN and CNBr under the above conditions are shown in the accompanying graphs.

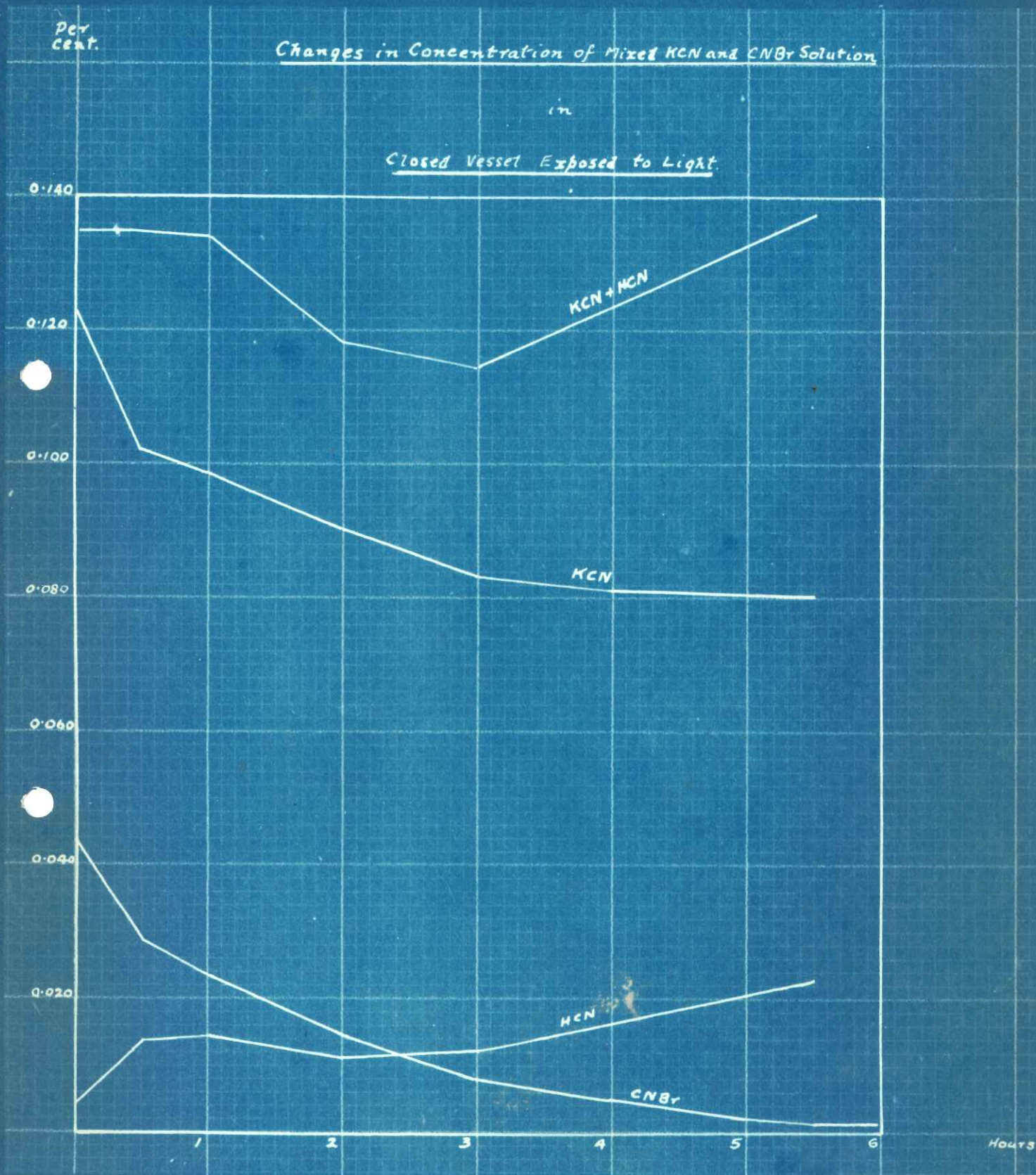
Changes in Concentration of Mixed KCN and CNBr Solution

in

Open Vessel Exposed to Light



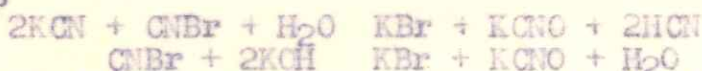
(13 a)



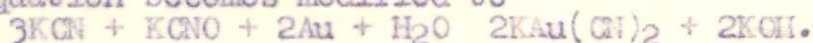
Glennell, in attempting to give a theoretical explanation of the above decompositions puts forward the following facts as leading to this explanation -

- (a) hydrocyanic acid is a product of the decomposition,
- (b) the amount of cyanogen present as potassium cyanide and hydrocyanic acid remains constant throughout.

He proposes



and denies that there is any formation of alkali cyanide. The alkali cyanate, he says, possibly acts as an oxidising agent and Elsner's equation becomes modified to



Since the KOH formed is immediately attacked by CNBr the same effect is produced as that stated by Sulman, except that his equation shows the solution of two atomic proportions of gold by means of three molecular proportions of KCN and one molecular proportion of CNBr, while Glennell's equation shows the solution of two atomic proportions of gold by means of five molecular proportions of KCN and two molecular proportions of CNBr. The final effect may be expressed by

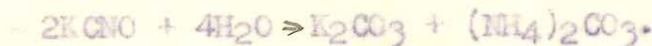


The thermal energy developed in Sulman's proposed reaction is less than in Elsner's reaction and therefore the greater activity of a mixed KCN and CNBr solution can not be accounted for by any explanation which depends on the quantity of energy produced during the reaction.

If Glennell is correct, the active agent is KCNO and not CNBr. Possibly the liberated HCN also plays a part



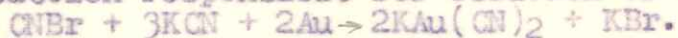
If potassium cyanate is the active agent, the question arises whether it is capable of accelerating the solvent action of KCN. Cyanogen bromide is generally considered to be incapable of dissolving gold, but is capable of acting as an accelerator. It may be possible, similarly, that potassium cyanate which is a slow solvent of gold, also accelerates the solvent action of KCN. It is, however, difficult to decide whether potassium cyanate acts as a supplier of oxygen and in this way accelerates the action of potassium cyanide because potassium cyanate is readily decomposed by water



Sulman and Teed in a paper on "The Sulman-Teed (Bromocyanide) Process of Gold Extraction", Journal of the Society of Chemical Industry, Vol. XVI, 1896, after discussing the chemistry of the ordinary cyanide process which necessitates the presence of free oxygen in the solution, state that the inevitable defects in all air oxygenation - or chemical oxidation - cyanide processes are:-

- (a) the slow oxidation of pyrite and other base sulphides, with consequent destruction of cyanide and loss of oxygen;
- (b) the production of potassium hydroxide as a necessary reaction product of the solution of the gold.

They maintain that in the presence of sulphides of iron, copper, arsenic, lead, zinc, antimony, etc., the potassium hydroxide produces soluble metallic and sulphide compounds which react directly on the cyanide and destroy it. This, however, is open to question. The authors consider that rich pyritic ores and concentrates and ores containing arsenical or copper pyrites can not be treated by the ordinary cyanide process. They propose the use of cyanogen bromide as an accelerator ^{although} ~~it~~ is not an oxidising agent, and put forward as the main reaction responsible for solution of the gold



They say that no air is necessary, since oxygen takes no part in the reaction and no potassium hydroxide results from the reaction, and, although attempts have been made to prove this reaction to be a form of oxidation, all such theories require the intervention of

of hydrolysis which the authors state is impossible because of the instability of the cyanogen halides in dilute aqueous solution - below 1 per cent.

The paper gives a brief description of the application of the process to (a) battery tailings from a free-milling ore at Day Dawn Western Australia, and (b) massive arsenical pyrites carrying over 40 per cent. arsenic, at Deloro, Canada.

(a) Day Dawn battery tailings, minus 25 to 30 mesh, were treated without any preliminary wash of acid, alkali, or water. The cyanide and cyanogen bromide solutions were mixed immediately before use and the cyanogen bromide was proportioned to the work to be done, the cyanogen bromide not exceeding one-quarter of the potassium cyanide present. The ore was treated by leaching with the mixed solution (about one-third of the weight of the ore) and the liquor was circulated for two or three hours till fairly uniform in composition. The cyanide solution contained 0.1 per cent. KCN and 0.025 per cent. CNBr, the time of treatment was fourteen to fifteen hours, consumption of cyanide was 0.25 lb. and of cyanogen bromide 0.11 lb. per ton of ore. The percentage extraction was about ninety, the tailings being reduced from 3 - 4 dwt. down to 8 - 10 grains of gold per ton.

(b) At Deloro the ore assayed about 17.5 dwt. gold per ton and contained about 42 per cent. arsenic, 20 per cent. sulphur, and 38 per cent. iron. Two solutions were employed, a strong solution, 0.2 to 0.25 per cent. KCN, and a weak solution, 0.1 per cent. KCN, each with the necessary addition of cyanogen bromide. The consumption of cyanide was 1 lb. and of cyanogen bromide 0.33 lb. per ton of ore, while the percentage extraction was about ninety, when crushed to minus 35 to 40 mesh, and the total time of treatment was thirty to forty hours.

The authors state that the total cyanogen bromide need not be added all at once, but may be in two or more additions, during circulation, from time to time. This is found necessary when the extraction is prolonged. They also say that the dissolved gold salt in even dilute bromocyanide liquors is so stable that it is found convenient and desirable to make one charge of liquor extract several vats of ore in succession, without intermediate precipitation.

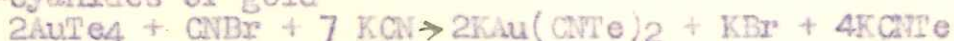
A. C. Claudet, during the discussion on the paper, stated that he had found that a very weak solution of potassium cyanide would extract as much gold as the authors claimed.

T. A. Rickard in a paper on the Cripple Creek Goldfield, *Trans. Inst. Mining & Metallurgy*, Vol. VIII, 1899, 1900, briefly reviews the different methods of treatment employed from time to time on the telluride ores of Cripple Creek. Bromocyanidation was not employed, but cyanidation of the roasted ore was found to be capable of yielding a high percentage extraction.

In a paper entitled "Notes on the Treatment of Kalgoorlie Sulpho-Telluride Ores" by Alfred James, *Trans. Inst. Mining & Metallurgy*, Vol. VIII, 1899, 1900, after showing that in some cases extractions up to 81 per cent. could be obtained by percolation treatment with plain cyanide solution after seventeen days' treatment, and 60 to 77 per cent. by agitation for sixteen and a half hours, the author points out the necessity for fine grinding, i.e., to minus 90 mesh, and agitation with the solution. Further experiments showed the need for still finer grinding, for the employment of an accelerator with agitation, or for the roasting of the ores, and that it was not possible on the rich ores to obtain a final extraction within a reasonable time, except by roasting or other special means. Agitation methods always showed better results than percolation. Comparative tests on minus 120 mesh ore by agitation with plain cyanide and with cyanide and cyanogen bromide showed that the latter treatment yielded 91.5 per cent. extraction

in twenty three hours while plain cyanide in four treatments of twenty three hours each gave only 68 per cent. extraction. On minus 40 mesh ore, plain cyanide gave 65 per cent. extraction after three treatments of twenty three hours each, while bromocyanide treatment yielded 78 per cent. extraction in twenty three hours. Therefore, fine grinding is essential.

H. L. Sulman, in the course of the discussion, said that the ideal equation for the action of cyanogen bromide and potassium cyanide on telluride of gold seemed to require the formation of telluro-cyanides of gold

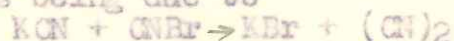


although his own and Picard's experiments had not definitely proved the formation of telluro-cyanides, but rather pointed to a hydrolytic action which produced tellurous acid (i.e., soluble tellurites) and hydrocyanic acid.

In his book, "Cyanide Practice", Alfred James, in dealing with "The Treatment of Sulpho-telluride Ores", reprints his paper summarised above and adds nothing to the knowledge of the treatment by cyanogen bromide. Later, in the same work, he discusses at some length the action of cyanogen bromide under the heading of "Bromocyanide". In this section he states generally, that -

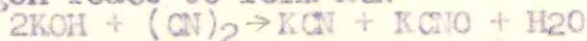
- (i) The addition of cyanogen bromide to a solution of potassium cyanide in the proportion of preferably not more than one of the former to four of the latter, effects a considerable acceleration in the rate of solution of the gold over that of the simple cyanide solution, although it may not affect the final percentage of extraction.
- (ii) The addition of cyanogen bromide causes a greater consumption or loss of cyanogen than the simple cyanide process, except in those cases where the treatment by the simpler process is ineffective or requires to be considerably prolonged, or where the presence of such minerals as marcasite may render a rapid treatment advisable, and thus prevent the formation of alkaline sulphide, which tends to retard or lessen the extraction by the simple cyanide process.

He advises the addition of the cyanogen bromide in portions, say, every two hours, as, in the presence of cyanide solution, decomposition is rapid, being completed in from three to six hours. He explains the decomposition of cyanogen bromide by a solution of potassium cyanide as being due to



and in confirmation of this hypothesis gives the following data :- "1000 grains of 0.4 per cent. CNBr solution were mixed with 1000 grains of 0.24 per cent. KCN solution and left standing over night. The results, when tested, showed that complete reaction had taken place as no CNBr or KCN could be discovered in the solution. On adding excess of KOH, however, the presence of KCN was discovered to the extent of 0.12 per cent., thus showing that cyanogen was present in the solution".

Unfortunately for this explanation, James neglects to prove definitely that cyanogen was present in the solution and although he found no KCN in the solution, yet found 0.12 per cent. after adding excess of KOH. This does not take into account the possibility of the cyanogen being present in the solution in the form of hydrocyanic acid, the presence of which had previously been proved by other investigators, nor does he explain the reaction by which KOH and cyanogen react to form KCN



In addition, the mixed solution used for testing contained a very much greater ratio of CNBr to KCN than the solutions used in practice or than the solution recommended by James himself in his general statement quoted above that this ratio should not be greater than one to four. Hence, this test is of no value from a practical point of view, nor do his conclusions appear to be warranted by the results of his test.

James' experiments on the decomposition of CNBr in mixed

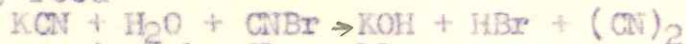
solutions of KCN and CNBr showed that in strong cyanide solutions (0.2 to 0.8 per cent. KCN), decomposition of CNBr was very rapid when the ratio of CNBr to KCN was one to two or one to four, and he therefore concluded that the destruction of CNBr increased with an increase with the proportion of KCN.

He also observed that CNBr decomposed much more rapidly if alkali hydroxide were present in addition to KCN.

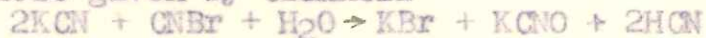
In addition, he noted that the KCN was also decomposed. This, of course, was certain to take place whether the equation given by James



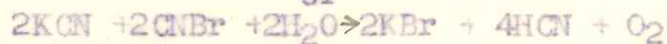
or that given by Teed



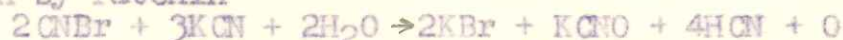
or either of those given by Clennell



or

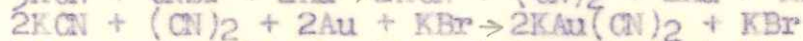
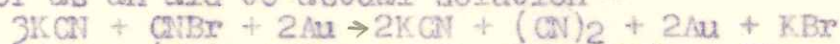


or that given by Patchin



is correct. James and Teed give no reliable data in support of their proposed reactions, whereas Clennell and Patchin support their conclusions with the results of experimental determinations.

James apparently adheres to the idea that in mixed solutions of KCN and CNBr, cyanogen is the dissolving agent, for he gives the following equations in explanation of the action of the CNBr as an accelerator or as an aid to actual solution -



and supports this assumption by the statement that the power of attack of the cyanogen radicle at the moment of formation on the gold present is the cause of a marked acceleration of the extraction rate over that of ordinary solutions. This conclusion is directly opposed to the well known fact, proved by Skey, (Engineering and Mining Journal, 1897, p. 163) that cyanogen is not a solvent of gold, although it may be an accelerator of the solvent action of KCN.

James also shows that air is unnecessary for the solution of gold in the presence of CNBr and that the addition of air causes no improvement in extraction where CNBr is concerned. He concludes this section by reiterating his view regarding the accelerating action of CNBr when he says that the "explanation is undoubtedly the remarkable power of the molecule $(\text{CN})_2$ when in contact with gold or certain gold-bearing minerals at the period of its dissociation or nascency. *** The remarkable efficiency of this reagent is due to the production of the molecule of cyanogen in contact with the material to be treated".

H. Knutsen (Proc. Inst. MIN. & Met., Vol. XII, 1902) describes the "Diehl" process which was the name given to the process worked out by Dr. L. H. Diehl for the treatment of the sulpho-telluride ores of the Kalgoorlie mines. This is apparently the first published account of the treatment of slimed ore by the process, which had previously been applied almost entirely to the leaching of sand or sand and slime by percolation.

In this paper Knutsen describes the process as consisting of three main operations, viz.,

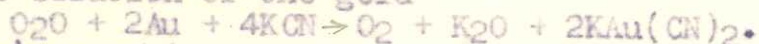
- (1) crushing and sliming the ore.
- (2) treating the slimes in agitators with KCN solution in combination with CNBr.
- (3) filterpressing the sludge and precipitating the gold.

He states, further, that amalgamation and concentration can be added according to the nature of the ore.

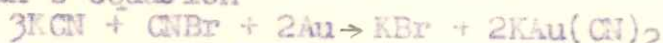
At the time of the publication of this paper the ores treated in the mills of the Kalgoorlie mines were invariably rich ores assaying from 1 to 3 ounces gold per ton. To the slime pulp containing 40 to 50 per cent. of dry ore, by weight, strong KCN solution was added to bring the concentration of the solution up to the equivalent of 4.4 lb. KCN per ton of ore. The pulp was then agitated for 1 - 1½ hours, at the end of which period CNBr was added in the proportion of 1.1 lb. per ton of ore. Agitation was

continued until the total time of treatment reached twenty four hours, when the pulp was discharged from the agitators to the filter presses. Two hours before discharging the pulp from the agitators, lime was added in the proportion of one to four pounds per ton of dry slime for the purpose of obtaining a clean precipitate in the zinc boxes.

In attempting to describe the chemistry of the process, Knutsen gives his opinion that "it is not pure oxygen which liberates cyanogen, but its allotropic form, ozone, which is known to occur in water, and especially where water is evaporating". He ~~even~~ evidently considers that the active agent in a cyanide solution used for dissolving gold is free cyanogen liberated from the KCN for he says "the effect of ozone on potassium iodide is well known, and I suppose it has an analogous effect on potassium cyanide". He gives as the reaction for the solution of the gold



In giving Sulman's equation



he says that CNBr not only liberates one molecule of cyanogen from the KCN but at the same time gives off its own cyanogen, so that he evidently considers that it is the free cyanogen which causes the gold to dissolve. This view we know to be erroneous since cyanogen is not a solvent for gold (Skey, E. & M. J., 1897, p. 163). He draws attention also to the fact that gold is insoluble in air-free cyanide and cyanogen bromide solutions but is readily soluble in the mixed solution.

Knutsen gives brief details of the practice on three mines using the Diehl process, viz., Hannan's Star, Lake View Consols, and Hannan's Brown Hill mines. A summary of these details is given below.

<u>Hannan's Star.</u>	KCN in solution	0.15 per cent. of the dry ore
	CNBr in solution	0.04 per cent. of the dry ore
	CaO added	3 - 4 lb. per ton of dry ore
	Residues from 14 dwt. ore	14 - 18 gr. per ton
	Cost	2 1/4 per ton of ore
	Consumption of KCN	2 lb. per ton of ore
	Consumption of CNBr	0.5 lb. per ton of ore.

Lake View Consols.

~~Amalgamation and~~ Concentration preceded cyanidation and the table residues were slimed preparatory to bromocyanidation.

KCN in solution, 4.4 lb. per ton of ore = 0.2 % KCN
 CNBr in solution, 0.05 per cent. of the ore
 CaO added, 3 - 4 lb. per ton of ore
 Residues after 24 hours' agitation, 1.5 - 2.5 dwt. per ton
 Cost, 27/9 per ton of ore.
 This process was run in comparison with the roasting process, the cost of which was 31/4 per ton of ore.

Hannan's Brown Hill.

Amalgamation and concentration preceded cyanidation. Treatment was similar to that at the Lake View Consols.
 Consumption of KCN, 3 lb. per ton of ore
 Consumption of CNBr, 1.25 lb. per ton of ore
 Cost, 20/- per ton, including concentration and treatment of concentrates (3 - 5 per cent. of the ore).

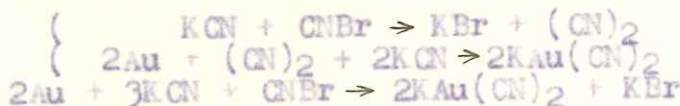
The main points of importance in Knutsen's paper are

- (1) the method of application of the CNBr, viz., its addition after 1 - 2 hours' agitation with KCN,
- (2) addition of lime two hours before discharging the agitator to the filter press.

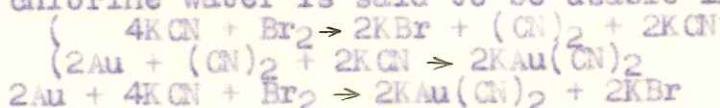
Although he does not specifically say so, presumably, no lime was added to the ore or pulp until two hours before discharging the agitator, so it must be assumed that he was fully aware of the deleterious action of caustic ~~alkali~~ alkali on the cyanogen bromide and of the necessity for keeping the alkalinity of the solution as low as possible during bromocyanidation. These two points are those to which most attention must be paid in this method of treatment.

Donald Clark, Australian Mining and Metallurgy, 1904, describes the Diehl process which was then in operation at Hannan's Star, Lake View Consols, and Hannan's Brown Hill mines. The only points worthy of note are that the ratio of cyanogen bromide to potassium cyanide should not exceed 1 to 4 and that alkaline solutions may not be used when cyanogen bromide is added.

Schnabel and Louis - Handbook of Metallurgy, 1905 - in dealing with the chemical reactions involved in the cyanide process, give a list of oxidising agents which promote solution and then state that cyanogen bromide is a powerful reagent which reacts with potassium cyanide to form cyanogen, which, in turn, reacts directly with gold



Bromine or chlorine water is said to be usable instead of CNBr



They state that one part by weight of oxygen, bromine, or chlorine dissolves respectively 24.5, 2.5, and 5.52 parts by weight of gold, so that oxygen is more efficient, weight for weight, than the other two elements. They conclude by saying that as, in practice, weak solutions of KCN are used, the volume of the ore is great and the quantity of gold in it small, special oxidising agents are unnecessary.

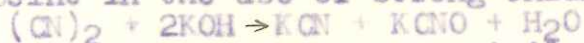
In "West Australian Metallurgical Practice", 1906, Robert Allen describes the practice on the mines then employing cyanogen bromide.
Oroya Brownhill.

After removal of about six per cent. of concentrate, the reground sands were agitated in covered vats with 0.1 per cent. cyanide solution for 3 hours, then CNBr in the proportion of about one pound to each ounce of gold was added and agitation continued a further 12 hours. About 2 hours before the end of the agitation period, 2 - 5 lb. CaO per ton were added. The consumption of KCN was 0.75 - 1 lb. per ton of ore, while the whole of the CNBr was destroyed. The pulp was then filter-pressed.

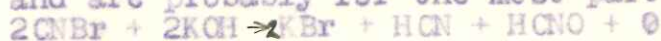
Lake View Consols.

After concentration, the table residues were reground to 80 per cent. minus 200 mesh and agitated for 12 - 16 hours with 0.075 per cent. KCN solution in agitators holding 60 tons of dry slime. Fifteen minutes after the addition of the KCN, 25 lb. CNBr were added. The consumption of KCN was 1 lb. per ton, while the whole of the CNBr was destroyed. The pulp was then filter-pressed.

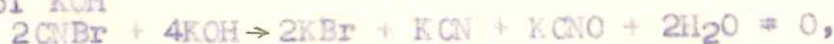
In "Cyaniding Gold and Silver Ores", 1907, Julian and Smart state that the only action of cyanogen bromide of value is that of an oxidising agent. They agree that it probably liberates cyanogen, like other oxidising agents, but, as pointed out by Skey, "aqueous solutions of cyanogen do not exert the least solvent action on gold and silver". The liberation of cyanogen, they point out, is really a weak point in the use of strong oxidisers



The reactions occurring, they state, are similar to those of other oxidising agents and are probably for the most part as follows:-



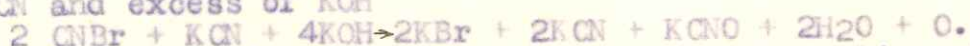
or, with excess of KOH



with KCN



or, with KCN and excess of KOH

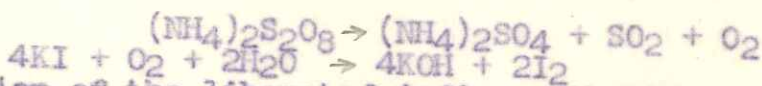


They quote from Knutsen's paper the practice at Kalgoorlie, which has already been reviewed.

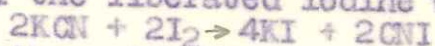
E. W. Nardin - Trans. Aust. Inst. Min. Eng., Vol. XII, 1907 - states that the first bromocyanide plant erected in Western Australia was at Hamman's Star mine, where a 91 per cent. extraction on a 15 dwt, sulphide ore was guaranteed and was obtained. The ore was ground in tube mills to minus 150 mesh and agitated with cyanide solution for three hours, when the charge of CNBr was added. After a total agitation of twenty hours, lime was added and the charge pressed. Nardin suggests as the result of his experiments :-

1. The daily ore sample should be taken in the morning and assayed as soon as possible, so as to know the value of the ore passing to the vats in the previous twenty four hours.
2. The pulp should have a long treatment with cyanide.
3. A vat should be kept under cyanide treatment till the ^{gold content} value of the $\frac{1}{2}$ cyanide residue is known.
4. The alkalinity of the vat should then be determined and corrected to 0.01 per cent. by sulphuric acid before adding CNBr.
5. The quantity of CNBr should then be determined from the value of the cyanide residue, the tonnage of the vat, etc.
6. The lime added to the ore during crushing should be varied according to the alkalinity test after cyanide treatment, so that the plant solution tests about 0.02 per cent.
7. Lime water should be made and added to the vats or to the solution from the presses, instead of adding lime to the vats.
8. Metallic iron should be kept out of the pulp as far as possible as it is both a cyanicide and a bromo-cyanicide.

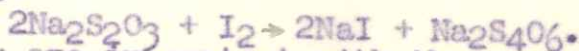
In a communication to the Chemical, Metallurgical and Mining Society of South Africa by the Portland Metallurgical Society, (edited by Thos. B. Crowe) - Jour. Chem. Met. & Min. Soc. S. Africa, May, 1909 - describing researches on the telluride gold ores of Cripple Creek, after dealing with the action of alkali persulphates as oxidising agents in the cyanide process, the production of cyanogen iodide by the action of alkali persulphates on potassium iodide



and combination of the liberated iodine with KCN



is described, together with the use of cyanogen iodide as an accelerator of the solution of gold by KCN. When excess of alkali was avoided it was found that in the treatment of ore, good residues, of less than 1 dwt, per ton, were invariably obtained from one ounce ore ground to 100 mesh, by treatment with a solution containing 1 lb. KCN, 1 lb. KI, 3 lb. alkali persulphate per ton of solution in a pulp of 3 solution to 1 ore, and that the consumption of KCN was about 1 lb. per ton of ore. The solutions, after leaving the ore and standing in contact with the air, lost their cyanide. This loss was more pronounced when testing heavy sulphide ores, possibly owing to formation of sodium thiosulphate by the action of the persulphate on pyrite, and the oxidation of sodium thiosulphate to sodium tetrathionate by iodine



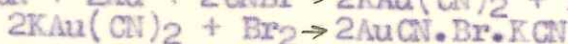
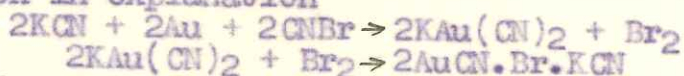
When the solutions are in contact with the ore, the reducing action of the ore assists in overcoming oxidising influences, but, when separated, the oxidation becomes more vigorous.

In the course of the ensuing discussion, Dr. J. Moir characterised the first equation as ridiculous because ammonium persulphate does not yield sulphur dioxide under any circumstances; he also ridicules the production of iodine in alkaline solution by the action of ammonium persulphate on potassium iodide. The statement about the formation of sodium thiosulphate by the action of ammonium persulphate on pyrite has no foundation in fact as the only conceivable products from pyrite are sulphur dioxide and sulphuric acid.

T. B. Stevens suggested that from a chemical standpoint only, cyanogen iodide would probably be more efficient than cyanogen bromide as the action of the iodide would be slower and therefore more prolonged. Cyanogen bromide, he states to be completely decomposed three hours after addition to the ore pulp. He considers that the high cost of

decomposed three hours after addition to the ore pulp. He considers that the high cost of potassium iodide and ammonium persulphate would render the use of cyanogen iodide prepared by the suggested method out of the question.

S. H. Worrell - Chemistry of the Bromo-Cyanogen Process, M. & Sci. Press, March 6th, 1909 - describes work done to determine what actually happens in the dissolution of gold by KCN and CNBr solution. C. P. CNBr and pure finely divided gold were prepared, and KCN, 98 per cent. was used. Comparative tests were then carried out with these materials to determine the weight of gold dissolved compared with the amount of KCN consumed in tests with and without the addition of CNBr. Worrell found that in two sets of tests twice as much gold was dissolved with the same consumption of KCN when CNBr was used instead of atmospheric oxygen. He then suggests the following reaction in explanation



and cites Bull. de Soc. Chem., Ser. 1, pp. 29 - 416 (Paris) as authority that $\text{KAu}(\text{CN})_2$ readily forms absorption products with the halogens.

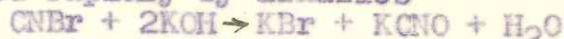
Unfortunately, Worrell's tests were not carried out under similar conditions, for in his first test with straight KCN solution (0.5 per cent. KCN), agitation was carried out by drawing air through the solution for 6 - 8 hours, which is a somewhat indefinite period, while in the parallel test with CNBr added, agitation was carried out intermittently from 2 - 4 hours, another indefinite period, which is not the same as that for the corresponding test with straight KCN. He also gives no information as to the manner of carrying out the agitation in the CNBr test, i.e., whether agitation was by air, which appears unlikely, or was carried out in a closed vessel with a minimum of air or in an open vessel with free access of air. All these points should have been stated to enable a fair comparison to be made. No reference is made to the alkalinity or acidity of the KCN + CNBr solution, factors of vital importance. Therefore, although his explanation is ingenious and quite possible, further confirmation is required in the form of series of parallel tests carried out under exactly similar conditions with the two solutions. Tests, using C. P. substances, while giving information of value in determining theoretically the action of the solvents, may give results entirely different from those obtained in large scale treatment, where the use of C. P. chemicals is impracticable. From a practical point of view, results obtained with solutions similar to those used in mill practice, are of more value than results obtained with pure solutions, since the action of the solvent may be modified or affected by the presence in the solution of other substances resulting from the method of preparation of the solvent or by the presence in the ore undergoing treatment of various minerals which may or may not have an influence on the efficiency of the solvent.

Clennell - Cyanide Handbook, 1910 - in dealing with the chemistry of cyanogen bromide, quotes the following reactions of this compound :-

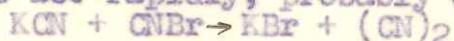
(1) It is gradually decomposed by water



(2) It is decomposed rapidly by alkalis



(3) Soluble cyanides act rapidly, probably evolving cyanogen



possibly also

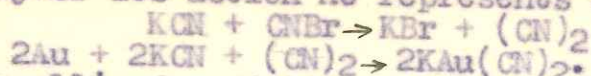


The liberation of cyanogen in an active form appears to be the cause of the rapid solvent power of a mixed solution of KCN and CNBr on gold



In describing the process Clennell points out that CNBr must be used in solutions containing little or no free alkali, that it is most effective if added in small quantities at a time,

and that cyanogen bromide is not, per se, a solvent of gold. The simplest theory of its action he represents thus :-



Clennell's description of the method of treatment of the sulpho-telluride ores of Kalgoorlie is similar to that given in previous publications.

M. W. vonBernewitz - M. & Sci. Press, 7th May, 1910 - gives information regarding the tonnages treated by bromocyanidation, extraction and costs at the mills at Kalgoorlie using this process.

Lake View Consols	- 11200 tons per month, 90 per cent extraction, cost 10/3 per ton.
Oroya Links Ltd.	- 11500 tons per month, 92 per cent. extraction, cost 10/2 per ton.
Golden Horseshoe	- 17000 tons per month, 90 per cent. extraction, cost 11/8 per ton.
Ivanhoe	- 10000 tons per month, slightly under 90 per cent. extraction, cost 7/11 per ton.

He states that in the wet crushing process the extraction would be low if cyanogen bromide were not used, since certain minerals in the ore are soluble in KCN + CNBr solution but not in plain KCN solution.

Rand Metallurgical Practice, Vol. I, 1911, describes the process as being applicable to ores from which the ordinary cyanide process fails to secure a sufficiently high percentage extraction. The method of testing ores with KCN + CNBr solution is described. Sliming of the ore is recommended, together with agitation for twenty four hours with free access of air with 0.25 per cent. KCN solution and 1 per cent. of lime. After 24 hours' agitation, the charge is tested for alkalinity as it has been found that the highest extractions are obtained when the alkalinity of the solution, before addition of CNBr, approximates and does not exceed 0.01 per cent. NaOH. If necessary, the alkalinity is reduced to this by addition of sulphuric acid. Cyanogen bromide solution is added to bring the total up to 0.01 per cent. CNBr and agitation is continued in a closed vessel for 3 - 4 hours. The charge is then filtered and washed. Instructions are given for preparing small quantities of CNBr solution and for testing for CNBr.

Gerard W. Williams - "Metallurgy of the Kalgoorlie Goldfield, E. & M. J., LXXXV, 7, 15th Feb., 1908 - describes briefly the treatment at several of the mills on the Kalgoorlie mines. The only information of value in connection with bromocyanidation is given in the description of the treatment at the mill of the Ivanhoe Gold Corporation, wherein it is stated that the slimes produced by re-grinding the residues from the concentrating tables are diluted with weak solution in the ratio of one of ore to one of solution and agitated for two hours, followed by addition of 0.6 lb. CNBr per ton of ore and continuation of agitation for 12 hours. Lime - 1 lb. per ton of dry ore - was then added and the slimes were filter-pressed. The gold recovered was as follows :- by amalgamation, 28 per cent.; from concentrates, 13 per cent.; from sands, 17.5 per cent.; from slimes, 28.5 per cent., while 13.5 per cent. was left in the residues. Treatment costs were 9/2 per ton of ore.

It is difficult to understand why, if this description is correct, agitation was continued for so long a period after addition of CNBr, because it appeared to be well known at that time that in a mixed solution of KCN and CNBr during agitation with the ore, practically the whole of the CNBr was destroyed during the first two or three hours, and therefore for the remainder of the time the ore was subject to the action of a plain cyanide solution only. Unfortunately, figures are not given in this article, nor in other similar articles, showing the proportion of the gold extracted by plain cyanide solution before addition of CNBr, which figures would have enabled a determination to be made of the time of agitation necessary to be adopted during the two periods.

In view of work done during 1927 by the writer and C. E. Blakett, it is significant that only two hours' agitation with plain

cyanide was considered necessary before adding CNBr, for this later work has shown that a somewhat similar short period of agitation with plain cyanide and an additional very short period of agitation after addition of CNBr are sufficient to enable an extraction of 90 per cent., and over, of the gold to be made by this method of treatment.

Gerard W. Williams - Westralian Wet-Crushing Plants, Jour. Chem. Met. & Min. Soc. S. Africa, Vol. VIII, 1908 - briefly describes the treatment at the Lake View mill, where the vats hold 60 tons of slime. The pulp, 1 of ore to 1 of solution is agitated 24 hours in KCN solution of concentration 0.06 per cent. KCN. During agitation the KCN falls to 0.04 per cent. and is brought up to 0.075 per cent, and, after 15 minutes' agitation, 25 lb. CNBr are added. After 12 - 16 hours' agitation, lime is added to neutralise the acidity and the vats are discharged for filter-pressing. The consumption of cyanide, including the cyanide in the cyanogen bromide solution, averages 1.4 lb. per ton.

W. E. Simpson - Trans. Inst. Min. & Met., Vol. XIII, 1903 - in an article on the Treatment of Telluride Ores by Dry Crushing and Roasting at Kalgoorlie, states that the Diehl process, on more than one occasion, a charge of sulphuric acid has been accidentally run in with the pulp into an agitator vat, in mistake for CNBr, and the agitation continued for some time before the error was detected; and it was found that the extraction from that particular vat was distinctly better than that obtained from the rest of the pulp under treatment. He states that "the Diehl vats are all covered in, to the complete exclusion of atmospheric oxygen, which seems in direct defiance of the ordinary run of cyanide practice; but then the CNBr, added during the agitation, is in itself a powerful oxidiser, and more than makes up for any lack of aeration".

The Mineral Industry for 1901, Vol. X, states that 653 tons of sulphide ore, assaying 1.51 - 3.5 oz. gold per ton, were treated at the Brown Hill mill, yielding an extraction of 95.7 per cent. and that results as high as 97.6 per cent. are said to have been obtained. The consumption of CNBr was 0.5 - 1 lb. per ton of ore.

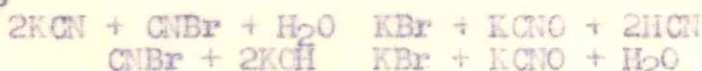
There is also given a resume of a paper by Wright before the Canadian Mining Institute, 1901, on the treatment of mispickel ores at Deloro, Canada :- The wet concentrates from the mill consist principally of mispickel, some iron pyrites, with small amounts of copper and from 15 to 20 per cent. of quartz sands. These are dumped directly into the vats to a depth of 3 feet (equivalent to about 40 tons) and a little lime added. After levelling, the charge is sampled. A short water wash is then given and as soon as the water has disappeared from the top of the ore the mixture of KCN and CNBr is run on, to an amount approximately one-third the weight of the ore. The wash water still draining out is run through zinc boxes until, on testing the solution with ferric chloride, a distinct blue colour is obtained. The solution is then switched to the strong solution tank. Constant slow percolation has been found to yield the best results, so, the solution after it runs through, is brought up to strength and continued in circulation for twenty four hours. By this time 60 - 70 per cent. of the gold has been extracted and it has been found advisable at this point to drain the charge and then turn it over by shovelling so as to break up and mix any lumps that may be present. The cyanide solution is again run on and the leaching continued until assays show the extraction to be complete. A weak cyanide wash is then given, followed by one of water only. Consumption per ton of concentrate - KCN, 2 lb., CNBr, 0.5 lb. Time of Treatment, 80 - 100 hours; extraction of gold, 87 - 94 per cent.

Mineral Industry, Vol. XI, 1902 contains articles by Philip Argall on "Cyaniding Sulpho-Telluride Ores" and by W. A. Prichard and H. C. Hoover on "Treatment of Sulpho-Telluride Ores at Kalgoorlie". The former considers CNBr to be a cyanogen liberator and that the tellurides are attacked by the very active nascent cyanogen. The latter paper briefly describes the Diehl process as in operation at the Lake View mill and give the extractions as follows :- Oroya Brownhill, 92.3 per cent.; Lake View, 90 per cent.; Hannan's Star, 91 - 92 per cent.

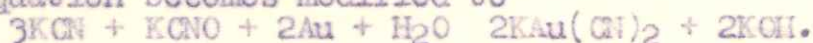
Glennell, in attempting to give a theoretical explanation of the above decompositions puts forward the following facts as leading to this explanation -

- (a) hydrocyanic acid is a product of the decomposition,
- (b) the amount of cyanogen present as potassium cyanide and hydrocyanic acid remains constant throughout.

He proposes



and denies that there is any formation of alkali cyanide. The alkali cyanate, he says, possibly acts as an oxidising agent and Elsner's equation becomes modified to



Since the KOH formed is immediately attacked by CNBr the same effect is produced as that stated by Sulman, except that his equation shows the solution of two atomic proportions of gold by means of three molecular proportions of KCN and one molecular proportion of CNBr, while Glennell's equation shows the solution of two atomic proportions of gold by means of five molecular proportions of KCN and two molecular proportions of CNBr. The final effect may be expressed by

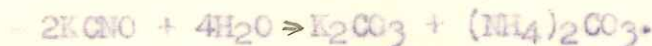


The thermal energy developed in Sulman's proposed reaction is less than in Elsner's reaction and therefore the greater activity of a mixed KCN and CNBr solution can not be accounted for by any explanation which depends on the quantity of energy produced during the reaction.

If Glennell is correct, the active agent is KCNO and not CNBr. Possibly the liberated HCN also plays a part



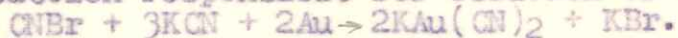
If potassium cyanate is the active agent, the question arises whether it is capable of accelerating the solvent action of KCN. Cyanogen bromide is generally considered to be incapable of dissolving gold, but is capable of acting as an accelerator. It may be possible, similarly, that potassium cyanate which is a slow solvent of gold, also accelerates the solvent action of KCN. It is, however, difficult to decide whether potassium cyanate acts as a supplier of oxygen and in this way accelerates the action of potassium cyanide because potassium cyanate is readily decomposed by water



Sulman and Teed in a paper on "The Sulman-Teed (Bromocyanide) Process of Gold Extraction", Journal of the Society of Chemical Industry, Vol. XVI, 1896, after discussing the chemistry of the ordinary cyanide process which necessitates the presence of free oxygen in the solution, state that the inevitable defects in all air oxygenation - or chemical oxidation - cyanide processes are:-

- (a) the slow oxidation of pyrite and other base sulphides, with consequent destruction of cyanide and loss of oxygen;
- (b) the production of potassium hydroxide as a necessary reaction product of the solution of the gold.

They maintain that in the presence of sulphides of iron, copper, arsenic, lead, zinc, antimony, etc., the potassium hydroxide produces soluble metallic and sulphide compounds which react directly on the cyanide and destroy it. This, however, is open to question. The authors consider that rich pyritic ores and concentrates and ores containing arsenical or copper pyrites can not be treated by the ordinary cyanide process. They propose the use of cyanogen bromide as an accelerator ^{although} ~~it~~ is not an oxidising agent, and put forward as the main reaction responsible for solution of the gold



They say that no air is necessary, since oxygen takes no part in the reaction and no potassium hydroxide results from the reaction, and, although attempts have been made to prove this reaction to be a form of oxidation, all such theories require the intervention of

of hydrolysis which the authors state is impossible because of the instability of the cyanogen halides in dilute aqueous solution - below 1 per cent.

The paper gives a brief description of the application of the process to (a) battery tailings from a free-milling ore at Day Dawn Western Australia, and (b) massive arsenical pyrites carrying over 40 per cent. arsenic, at Deloro, Canada.

(a) Day Dawn battery tailings, minus 25 to 30 mesh, were treated without any preliminary wash of acid, alkali, or water. The cyanide and cyanogen bromide solutions were mixed immediately before use and the cyanogen bromide was proportioned to the work to be done, the cyanogen bromide not exceeding one-quarter of the potassium cyanide present. The ore was treated by leaching with the mixed solution (about one-third of the weight of the ore) and the liquor was circulated for two or three hours till fairly uniform in composition. The cyanide solution contained 0.1 per cent. KCN and 0.025 per cent. CNBr, the time of treatment was fourteen to fifteen hours, consumption of cyanide was 0.25 lb. and of cyanogen bromide 0.11 lb. per ton of ore. The percentage extraction was about ninety, the tailings being reduced from 3 - 4 dwt. down to 8 - 10 grains of gold per ton.

(b) At Deloro the ore assayed about 17.5 dwt. gold per ton and contained about 42 per cent. arsenic, 20 per cent. sulphur, and 38 per cent. iron. Two solutions were employed, a strong solution, 0.2 to 0.25 per cent. KCN, and a weak solution, 0.1 per cent. KCN, each with the necessary addition of cyanogen bromide. The consumption of cyanide was 1 lb. and of cyanogen bromide 0.33 lb. per ton of ore, while the percentage extraction was about ninety, when crushed to minus 35 to 40 mesh, and the total time of treatment was thirty to forty hours.

The authors state that the total cyanogen bromide need not be added all at once, but may be in two or more additions, during circulation, from time to time. This is found necessary when the extraction is prolonged. They also say that the dissolved gold salt in even dilute bromocyanide liquors is so stable that it is found convenient and desirable to make one charge of liquor extract several vats of ore in succession, without intermediate precipitation.

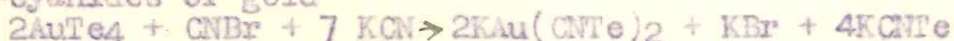
A. C. Claudet, during the discussion on the paper, stated that he had found that a very weak solution of potassium cyanide would extract as much gold as the authors claimed.

T. A. Rickard in a paper on the Cripple Creek Goldfield, *Trans. Inst. Mining & Metallurgy*, Vol. VIII, 1899, 1900, briefly reviews the different methods of treatment employed from time to time on the telluride ores of Cripple Creek. Bromocyanidation was not employed, but cyanidation of the roasted ore was found to be capable of yielding a high percentage extraction.

In a paper entitled "Notes on the Treatment of Kalgoorlie Sulpho-Telluride Ores" by Alfred James, *Trans. Inst. Mining & Metallurgy*, Vol. VIII, 1899, 1900, after showing that in some cases extractions up to 81 per cent. could be obtained by percolation treatment with plain cyanide solution after seventeen days' treatment, and 60 to 77 per cent. by agitation for sixteen and a half hours, the author points out the necessity for fine grinding, i.e., to minus 90 mesh, and agitation with the solution. Further experiments showed the need for still finer grinding, for the employment of an accelerator with agitation, or for the roasting of the ores, and that it was not possible on the rich ores to obtain a final extraction within a reasonable time, except by roasting or other special means. Agitation methods always showed better results than percolation. Comparative tests on minus 120 mesh ore by agitation with plain cyanide and with cyanide and cyanogen bromide showed that the latter treatment yielded 91.5 per cent. extraction

in twenty three hours while plain cyanide in four treatments of twenty three hours each gave only 68 per cent. extraction. On minus 40 mesh ore, plain cyanide gave 65 per cent. extraction after three treatments of twenty three hours each, while bromocyanide treatment yielded 78 per cent. extraction in twenty three hours. Therefore, fine grinding is essential.

H. L. Sulman, in the course of the discussion, said that the ideal equation for the action of cyanogen bromide and potassium cyanide on telluride of gold seemed to require the formation of telluro-cyanides of gold



although his own and Picard's experiments had not definitely proved the formation of telluro-cyanides, but rather pointed to a hydrolytic action which produced tellurous acid (i.e., soluble tellurites) and hydrocyanic acid.

In his book, "Cyanide Practice", Alfred James, in dealing with "The Treatment of Sulpho-telluride Ores", reprints his paper summarised above and adds nothing to the knowledge of the treatment by cyanogen bromide. Later, in the same work, he discusses at some length the action of cyanogen bromide under the heading of "Bromocyanide". In this section he states generally, that -

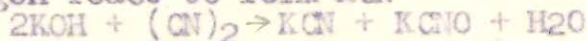
- (i) The addition of cyanogen bromide to a solution of potassium cyanide in the proportion of preferably not more than one of the former to four of the latter, effects a considerable acceleration in the rate of solution of the gold over that of the simple cyanide solution, although it may not affect the final percentage of extraction.
- (ii) The addition of cyanogen bromide causes a greater consumption or loss of cyanogen than the simple cyanide process, except in those cases where the treatment by the simpler process is ineffective or requires to be considerably prolonged, or where the presence of such minerals as marcasite may render a rapid treatment advisable, and thus prevent the formation of alkaline sulphide, which tends to retard or lessen the extraction by the simple cyanide process.

He advises the addition of the cyanogen bromide in portions, say, every two hours, as, in the presence of cyanide solution, decomposition is rapid, being completed in from three to six hours. He explains the decomposition of cyanogen bromide by a solution of potassium cyanide as being due to



and in confirmation of this hypothesis gives the following data :- "1000 grains of 0.4 per cent. CNBr solution were mixed with 1000 grains of 0.24 per cent. KCN solution and left standing over night. The results, when tested, showed that complete reaction had taken place as no CNBr or KCN could be discovered in the solution. On adding excess of KOH, however, the presence of KCN was discovered to the extent of 0.12 per cent., thus showing that cyanogen was present in the solution".

Unfortunately for this explanation, James neglects to prove definitely that cyanogen was present in the solution and although he found no KCN in the solution, yet found 0.12 per cent. after adding excess of KOH. This does not take into account the possibility of the cyanogen being present in the solution in the form of hydrocyanic acid, the presence of which had previously been proved by other investigators, nor does he explain the reaction by which KOH and cyanogen react to form KCN



In addition, the mixed solution used for testing contained a very much greater ratio of CNBr to KCN than the solutions used in practice or than the solution recommended by James himself in his general statement quoted above that this ratio should not be greater than one to four. Hence, this test is of no value from a practical point of view, nor do his conclusions appear to be warranted by the results of his test.

James' experiments on the decomposition of CNBr in mixed

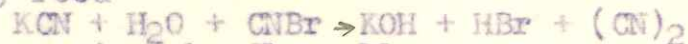
solutions of KCN and CNBr showed that in strong cyanide solutions (0.2 to 0.8 per cent. KCN), decomposition of CNBr was very rapid when the ratio of CNBr to KCN was one to two or one to four, and he therefore concluded that the destruction of CNBr increased with an increase with the proportion of KCN.

He also observed that CNBr decomposed much more rapidly if alkali hydroxide were present in addition to KCN.

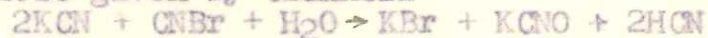
In addition, he noted that the KCN was also decomposed. This, of course, was certain to take place whether the equation given by James



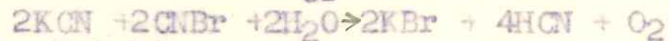
or that given by Teed



or either of those given by Clennell



or

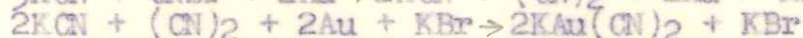
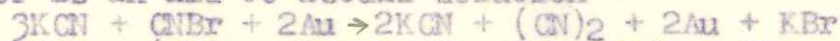


or that given by Patchin



is correct. James and Teed give no reliable data in support of their proposed reactions, whereas Clennell and Patchin support their conclusions with the results of experimental determinations.

James apparently adheres to the idea that in mixed solutions of KCN and CNBr, cyanogen is the dissolving agent, for he gives the following equations in explanation of the action of the CNBr as an accelerator or as an aid to actual solution -



and supports this assumption by the statement that the power of attack of the cyanogen radicle at the moment of formation on the gold present is the cause of a marked acceleration of the extraction rate over that of ordinary solutions. This conclusion is directly opposed to the well known fact, proved by Skey, (Engineering and Mining Journal, 1897, p. 163) that cyanogen is not a solvent of gold, although it may be an accelerator of the solvent action of KCN.

James also shows that air is unnecessary for the solution of gold in the presence of CNBr and that the addition of air causes no improvement in extraction where CNBr is concerned. He concludes this section by reiterating his view regarding the accelerating action of CNBr when he says that the "explanation is undoubtedly the remarkable power of the molecule $(\text{CN})_2$ when in contact with gold or certain gold-bearing minerals at the period of its dissociation or nascency. *** The remarkable efficiency of this reagent is due to the production of the molecule of cyanogen in contact with the material to be treated".

H. Knutsen (Proc. Inst. MIN. & Met., Vol. XII, 1902) describes the "Diehl" process which was the name given to the process worked out by Dr. L. H. Diehl for the treatment of the sulpho-telluride ores of the Kalgoorlie mines. This is apparently the first published account of the treatment of slimed ore by the process, which had previously been applied almost entirely to the leaching of sand or sand and slime by percolation.

In this paper Knutsen describes the process as consisting of three main operations, viz.,

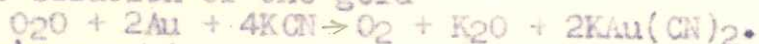
- (1) crushing and sliming the ore.
- (2) treating the slimes in agitators with KCN solution in combination with CNBr.
- (3) filterpressing the sludge and precipitating the gold.

He states, further, that amalgamation and concentration can be added according to the nature of the ore.

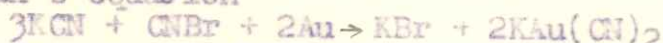
At the time of the publication of this paper the ores treated in the mills of the Kalgoorlie mines were invariably rich ores assaying from 1 to 3 ounces gold per ton. To the slime pulp containing 40 to 50 per cent. of dry ore, by weight, strong KCN solution was added to bring the concentration of the solution up to the equivalent of 4.4 lb. KCN per ton of ore. The pulp was then agitated for 1 - 1½ hours, at the end of which period CNBr was added in the proportion of 1.1 lb. per ton of ore. Agitation was

continued until the total time of treatment reached twenty four hours, when the pulp was discharged from the agitators to the filter presses. Two hours before discharging the pulp from the agitators, lime was added in the proportion of one to four pounds per ton of dry slime for the purpose of obtaining a clean precipitate in the zinc boxes.

In attempting to describe the chemistry of the process, Knutsen gives his opinion that "it is not pure oxygen which liberates cyanogen, but its allotropic form, ozone, which is known to occur in water, and especially where water is evaporating". He ~~even~~ evidently considers that the active agent in a cyanide solution used for dissolving gold is free cyanogen liberated from the KCN for he says "the effect of ozone on potassium iodide is well known, and I suppose it has an analogous effect on potassium cyanide". He gives as the reaction for the solution of the gold



In giving Sulman's equation



he says that CNBr not only liberates one molecule of cyanogen from the KCN but at the same time gives off its own cyanogen, so that he evidently considers that it is the free cyanogen which causes the gold to dissolve. This view we know to be erroneous since cyanogen is not a solvent for gold (Skey, E. & M. J., 1897, p. 163). He draws attention also to the fact that gold is insoluble in air-free cyanide and cyanogen bromide solutions but is readily soluble in the mixed solution.

Knutsen gives brief details of the practice on three mines using the Diehl process, viz., Hannan's Star, Lake View Consols, and Hannan's Brown Hill mines. A summary of these details is given below.

<u>Hannan's Star.</u>	KCN in solution	0.15 per cent. of the dry ore
	CNBr in solution	0.04 per cent. of the dry ore
	CaO added	3 - 4 lb. per ton of dry ore
	Residues from 14 dwt. ore	14 - 18 gr. per ton
	Cost	2 1/4 per ton of ore
	Consumption of KCN	2 lb. per ton of ore
	Consumption of CNBr	0.5 lb. per ton of ore.

Lake View Consols.

~~Amalgamation and~~ Concentration preceded cyanidation and the table residues were slimed preparatory to bromocyanidation.

	KCN in solution,	4.4 lb. per ton of ore = 0.2 % KCN
	CNBr in solution,	0.05 per cent. of the ore
	CaO added,	3 - 4 lb. per ton of ore
	Residues after 24 hours' agitation,	1.5 - 2.5 dwt. per ton
	Cost,	27/9 per ton of ore.

This process was run in comparison with the roasting process, the cost of which was 3 1/4 per ton of ore.

Hannan's Brown Hill.

Amalgamation and concentration preceded cyanidation. Treatment was similar to that at the Lake View Consols. Consumption of KCN, 3 lb. per ton of ore
Consumption of CNBr, 1.25 lb. per ton of ore
Cost, 20/- per ton, including concentration and treatment of concentrates (3 - 5 per cent. of the ore).

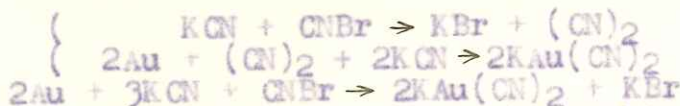
The main points of importance in Knutsen's paper are

- (1) the method of application of the CNBr, viz., its addition after 1 - 2 hours' agitation with KCN,
- (2) addition of lime two hours before discharging the agitator to the filter press.

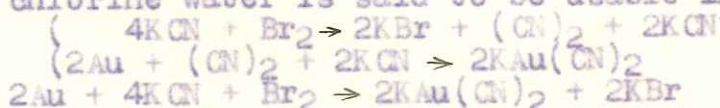
Although he does not specifically say so, presumably, no lime was added to the ore or pulp until two hours before discharging the agitator, so it must be assumed that he was fully aware of the deleterious action of caustic ~~alk~~ alkali on the cyanogen bromide and of the necessity for keeping the alkalinity of the solution as low as possible during bromocyanidation. These two points are those to which most attention must be paid in this method of treatment.

Donald Clark, Australian Mining and Metallurgy, 1904, describes the Diehl process which was then in operation at Hannan's Star, Lake View Consols, and Hannan's Brown Hill mines. The only points worthy of note are that the ratio of cyanogen bromide to potassium cyanide should not exceed 1 to 4 and that alkaline solutions may not be used when cyanogen bromide is added.

Schnabel and Louis - Handbook of Metallurgy, 1905 - in dealing with the chemical reactions involved in the cyanide process, give a list of oxidising agents which promote solution and then state that cyanogen bromide is a powerful reagent which reacts with potassium cyanide to form cyanogen, which, in turn, reacts directly with gold



Bromine or chlorine water is said to be usable instead of CNBr



They state that one part by weight of oxygen, bromine, or chlorine dissolves respectively 24.5, 2.5, and 5.52 parts by weight of gold, so that oxygen is more efficient, weight for weight, than the other two elements. They conclude by saying that as, in practice, weak solutions of KCN are used, the volume of the ore is great and the quantity of gold in it small, special oxidising agents are unnecessary.

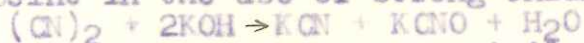
In "West Australian Metallurgical Practice", 1906, Robert Allen describes the practice on the mines then employing cyanogen bromide.
Oroya Brownhill.

After removal of about six per cent. of concentrate, the reground sands were agitated in covered vats with 0.1 per cent. cyanide solution for 3 hours, then CNBr in the proportion of about one pound to each ounce of gold was added and agitation continued a further 12 hours. About 2 hours before the end of the agitation period, 2 - 5 lb. CaO per ton were added. The consumption of KCN was 0.75 - 1 lb. per ton of ore, while the whole of the CNBr was destroyed. The pulp was then filter-pressed.

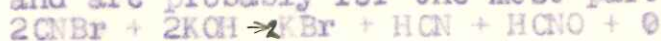
Lake View Consols.

After concentration, the table residues were reground to 80 per cent. minus 200 mesh and agitated for 12 - 16 hours with 0.075 per cent. KCN solution in agitators holding 60 tons of dry slime. Fifteen minutes after the addition of the KCN, 25 lb. CNBr were added. The consumption of KCN was 1 lb. per ton, while the whole of the CNBr was destroyed. The pulp was then filter-pressed.

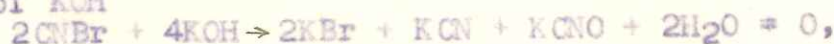
In "Cyaniding Gold and Silver Ores", 1907, Julian and Smart state that the only action of cyanogen bromide of value is that of an oxidising agent. They agree that it probably liberates cyanogen, like other oxidising agents, but, as pointed out by Skey, "aqueous solutions of cyanogen do not exert the least solvent action on gold and silver". The liberation of cyanogen, they point out, is really a weak point in the use of strong oxidisers



The reactions occurring, they state, are similar to those of other oxidising agents and are probably for the most part as follows:-



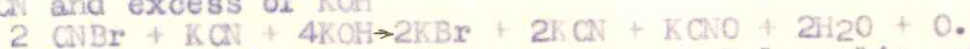
or, with excess of KOH



with KCN



or, with KCN and excess of KOH

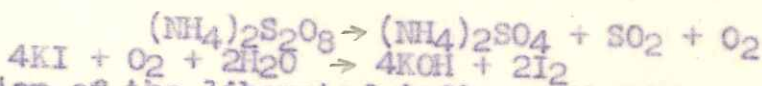


They quote from Knutsen's paper the practice at Kalgoorlie, which has already been reviewed.

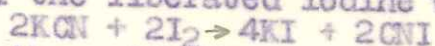
E. W. Nardin - Trans. Aust. Inst. Min. Eng., Vol. XII, 1907 - states that the first bromocyanide plant erected in Western Australia was at Hamman's Star mine, where a 91 per cent. extraction on a 15 dwt. sulphide ore was guaranteed and was obtained. The ore was ground in tube mills to minus 150 mesh and agitated with cyanide solution for three hours, when the charge of CNBr was added. After a total agitation of twenty hours, lime was added and the charge pressed. Nardin suggests as the result of his experiments :-

1. The daily ore sample should be taken in the morning and assayed as soon as possible, so as to know the value of the ore passing to the vats in the previous twenty four hours.
2. The pulp should have a long treatment with cyanide.
3. A vat should be kept under cyanide treatment till the ^{gold content} value of the $\frac{1}{4}$ cyanide residue is known.
4. The alkalinity of the vat should then be determined and corrected to 0.01 per cent. by sulphuric acid before adding CNBr.
5. The quantity of CNBr should then be determined from the value of the cyanide residue, the tonnage of the vat, etc.
6. The lime added to the ore during crushing should be varied according to the alkalinity test after cyanide treatment, so that the plant solution tests about 0.02 per cent.
7. Lime water should be made and added to the vats or to the solution from the presses, instead of adding lime to the vats.
8. Metallic iron should be kept out of the pulp as far as possible as it is both a cyanicide and a bromo-cyanicide.

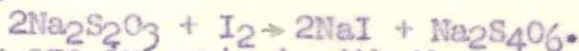
In a communication to the Chemical, Metallurgical and Mining Society of South Africa by the Portland Metallurgical Society, (edited by Thos. B. Crowe) - Jour. Chem. Met. & Min. Soc. S. Africa, May, 1909 - describing researches on the telluride gold ores of Cripple Creek, after dealing with the action of alkali persulphates as oxidising agents in the cyanide process, the production of cyanogen iodide by the action of alkali persulphates on potassium iodide



and combination of the liberated iodine with KCN



is described, together with the use of cyanogen iodide as an accelerator of the solution of gold by KCN. When excess of alkali was avoided it was found that in the treatment of ore, good residues, of less than 1 dwt. per ton, were invariably obtained from one ounce ore ground to 100 mesh, by treatment with a solution containing 1 lb. KCN, 1 lb. KI, 3 lb. alkali persulphate per ton of solution in a pulp of 3 solution to 1 ore, and that the consumption of KCN was about 1 lb. per ton of ore. The solutions, after leaving the ore and standing in contact with the air, lost their cyanide. This loss was more pronounced when testing heavy sulphide ores, possibly owing to formation of sodium thiosulphate by the action of the persulphate on pyrite, and the oxidation of sodium thiosulphate to sodium tetrathionate by iodine



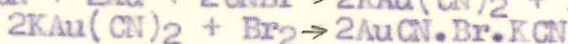
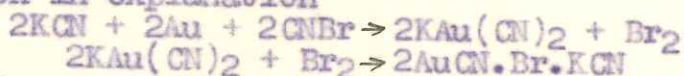
When the solutions are in contact with the ore, the reducing action of the ore assists in overcoming oxidising influences, but, when separated, the oxidation becomes more vigorous.

In the course of the ensuing discussion, Dr. J. Moir characterised the first equation as ridiculous because ammonium persulphate does not yield sulphur dioxide under any circumstances; he also ridicules the production of iodine in alkaline solution by the action of ammonium persulphate on potassium iodide. The statement about the formation of sodium thiosulphate by the action of ammonium persulphate on pyrite has no foundation in fact as the only conceivable products from pyrite are sulphur dioxide and sulphuric acid.

T. B. Stevens suggested that from a chemical standpoint only, cyanogen iodide would probably be more efficient than cyanogen bromide as the action of the iodide would be slower and therefore more prolonged. Cyanogen bromide, he states to be completely decomposed three hours after addition to the ore pulp. He considers that the high cost of cyanogen iodide is not justified.

decomposed three hours after addition to the ore pulp. He considers that the high cost of potassium iodide and ammonium persulphate would render the use of cyanogen iodide prepared by the suggested method out of the question.

S. H. Worrell - Chemistry of the Bromo-Cyanogen Process, M. & Sci. Press, March 6th, 1909 - describes work done to determine what actually happens in the dissolution of gold by KCN and CNBr solution. C. P. CNBr and pure finely divided gold were prepared, and KCN, 98 per cent. was used. Comparative tests were then carried out with these materials to determine the weight of gold dissolved compared with the amount of KCN consumed in tests with and without the addition of CNBr. Worrell found that in two sets of tests twice as much gold was dissolved with the same consumption of KCN when CNBr was used instead of atmospheric oxygen. He then suggests the following reaction in explanation



and cites Bull. de Soc. Chem., Ser. 1, pp. 29 - 416 (Paris) as authority that $\text{KAu}(\text{CN})_2$ readily forms absorption products with the halogens.

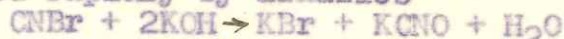
Unfortunately, Worrell's tests were not carried out under similar conditions, for in his first test with straight KCN solution (0.5 per cent. KCN), agitation was carried out by drawing air through the solution for 6 - 8 hours, which is a somewhat indefinite period, while in the parallel test with CNBr added, agitation was carried out intermittently from 2 - 4 hours, another indefinite period, which is not the same as that for the corresponding test with straight KCN. He also gives no information as to the manner of carrying out the agitation in the CNBr test, i.e., whether agitation was by air, which appears unlikely, or was carried out in a closed vessel with a minimum of air or in an open vessel with free access of air. All these points should have been stated to enable a fair comparison to be made. No reference is made to the alkalinity or acidity of the KCN + CNBr solution, factors of vital importance. Therefore, although his explanation is ingenious and quite possible, further confirmation is required in the form of series of parallel tests carried out under exactly similar conditions with the two solutions. Tests, using C. P. substances, while giving information of value in determining theoretically the action of the solvents, may give results entirely different from those obtained in large scale treatment, where the use of C. P. chemicals is impracticable. From a practical point of view, results obtained with solutions similar to those used in mill practice, are of more value than results obtained with pure solutions, since the action of the solvent may be modified or affected by the presence in the solution of other substances resulting from the method of preparation of the solvent or by the presence in the ore undergoing treatment of various minerals which may or may not have an influence on the efficiency of the solvent.

Clennell - Cyanide Handbook, 1910 - in dealing with the chemistry of cyanogen bromide, quotes the following reactions of this compound :-

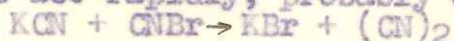
(1) It is gradually decomposed by water



(2) It is decomposed rapidly by alkalis



(3) Soluble cyanides act rapidly, probably evolving cyanogen



possibly also

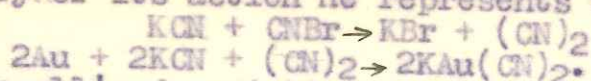


The liberation of cyanogen in an active form appears to be the cause of the rapid solvent power of a mixed solution of KCN and CNBr on gold



In describing the process Clennell points out that CNBr must be used in solutions containing little or no free alkali, that it is most effective if added in small quantities at a time,

and that cyanogen bromide is not, per se, a solvent of gold. The simplest theory of its action he represents thus :-



Clennell's description of the method of treatment of the sulpho-telluride ores of Kalgoorlie is similar to that given in previous publications.

M. W. vonBernewitz - M. & Sci. Press, 7th May, 1910 - gives information regarding the tonnages treated by bromocyanidation, extraction and costs at the mills at Kalgoorlie using this process.

Lake View Consols	- 11200 tons per month, 90 per cent extraction, cost 10/3 per ton.
Oroya Links Ltd.	- 11500 tons per month, 92 per cent. extraction, cost 10/2 per ton.
Golden Horseshoe	- 17000 tons per month, 90 per cent. extraction, cost 11/8 per ton.
Ivanhoe	- 10000 tons per month, slightly under 90 per cent. extraction, cost 7/11 per ton.

He states that in the wet crushing process the extraction would be low if cyanogen bromide were not used, since certain minerals in the ore are soluble in KCN + CNBr solution but not in plain KCN solution.

Rand Metallurgical Practice, Vol. I, 1911, describes the process as being applicable to ores from which the ordinary cyanide process fails to secure a sufficiently high percentage extraction. The method of testing ores with KCN + CNBr solution is described. Sliming of the ore is recommended, together with agitation for twenty four hours with free access of air with 0.25 per cent. KCN solution and 1 per cent. of lime. After 24 hours' agitation, the charge is tested for alkalinity as it has been found that the highest extractions are obtained when the alkalinity of the solution, before addition of CNBr, approximates and does not exceed 0.01 per cent. NaOH. If necessary, the alkalinity is reduced to this by addition of sulphuric acid. Cyanogen bromide solution is added to bring the total up to 0.01 per cent. CNBr and agitation is continued in a closed vessel for 3 - 4 hours. The charge is then filtered and washed. Instructions are given for preparing small quantities of CNBr solution and for testing for CNBr.

Gerard W. Williams - "Metallurgy of the Kalgoorlie Goldfield, E. & M. J., LXXXV, 7, 15th Feb., 1908 - describes briefly the treatment at several of the mills on the Kalgoorlie mines. The only information of value in connection with bromocyanidation is given in the description of the treatment at the mill of the Ivanhoe Gold Corporation, wherein it is stated that the slimes produced by re-grinding the residues from the concentrating tables are diluted with weak solution in the ratio of one of ore to one of solution and agitated for two hours, followed by addition of 0.6 lb. CNBr per ton of ore and continuation of agitation for 12 hours. Lime - 1 lb. per ton of dry ore - was then added and the slimes were filter-pressed. The gold recovered was as follows :- by amalgamation, 28 per cent.; from concentrates, 13 per cent.; from sands, 17.5 per cent.; from slimes, 28.5 per cent., while 13.5 per cent. was left in the residues. Treatment costs were 9/2 per ton of ore.

It is difficult to understand why, if this description is correct, agitation was continued for so long a period after addition of CNBr, because it appeared to be well known at that time that in a mixed solution of KCN and CNBr during agitation with the ore, practically the whole of the CNBr was destroyed during the first two or three hours, and therefore for the remainder of the time the ore was subject to the action of a plain cyanide solution only. Unfortunately, figures are not given in this article, nor in other similar articles, showing the proportion of the gold extracted by plain cyanide solution before addition of CNBr, which figures would have enabled a determination to be made of the time of agitation necessary to be adopted during the two periods.

In view of work done during 1927 by the writer and C. E. Blakett, it is significant that only two hours' agitation with plain

cyanide was considered necessary before adding CNBr, for this later work has shown that a somewhat similar short period of agitation with plain cyanide and an additional very short period of agitation after addition of CNBr are sufficient to enable an extraction of 90 per cent., and over, of the gold to be made by this method of treatment.

Gerard W. Williams - Westralian Wet-Crushing Plants, Jour. Chem. Met. & Min. Soc. S. Africa, Vol. VIII, 1908 - briefly describes the treatment at the Lake View mill, where the vats hold 60 tons of slime. The pulp, 1 of ore to 1 of solution is agitated 24 hours in KCN solution of concentration 0.06 per cent. KCN. During agitation the KCN falls to 0.04 per cent. and is brought up to 0.075 per cent, and, after 15 minutes' agitation, 25 lb. CNBr are added. After 12 - 16 hours' agitation, lime is added to neutralise the acidity and the vats are discharged for filter-pressing. The consumption of cyanide, including the cyanide in the cyanogen bromide solution, averages 1.4 lb. per ton.

W. E. Simpson - Trans. Inst. Min. & Met., Vol. XIII, 1903 - in an article on the Treatment of Telluride Ores by Dry Crushing and Roasting at Kalgoorlie, states that the Diehl process, on more than one occasion, a charge of sulphuric acid has been accidentally run in with the pulp into an agitator vat, in mistake for CNBr, and the agitation continued for some time before the error was detected; and it was found that the extraction from that particular vat was distinctly better than that obtained from the rest of the pulp under treatment. He states that "the Diehl vats are all covered in, to the complete exclusion of atmospheric oxygen, which seems in direct defiance of the ordinary run of cyanide practice; but then the CNBr, added during the agitation, is in itself a powerful oxidiser, and more than makes up for any lack of aeration".

The Mineral Industry for 1901, Vol. X, states that 653 tons of sulphide ore, assaying 1.51 - 3.5 oz. gold per ton, were treated at the Brown Hill mill, yielding an extraction of 95.7 per cent. and that results as high as 97.6 per cent. are said to have been obtained. The consumption of CNBr was 0.5 - 1 lb. per ton of ore.

There is also given a resume of a paper by Wright before the Canadian Mining Institute, 1901, on the treatment of mispickel ores at Deloro, Canada :- The wet concentrates from the mill consist principally of mispickel, some iron pyrites, with small amounts of copper and from 15 to 20 per cent. of quartz sands. These are dumped directly into the vats to a depth of 3 feet (equivalent to about 40 tons) and a little lime added. After levelling, the charge is sampled. A short water wash is then given and as soon as the water has disappeared from the top of the ore the mixture of KCN and CNBr is run on, to an amount approximately one-third the weight of the ore. The wash water still draining out is run through zinc boxes until, on testing the solution with ferric chloride, a distinct blue colour is obtained. The solution is then switched to the strong solution tank. Constant slow percolation has been found to yield the best results, so, the solution after it runs through, is brought up to strength and continued in circulation for twenty four hours. By this time 60 - 70 per cent. of the gold has been extracted and it has been found advisable at this point to drain the charge and then turn it over by shovelling so as to break up and mix any lumps that may be present. The cyanide solution is again run on and the leaching continued until assays show the extraction to be complete. A weak cyanide wash is then given, followed by one of water only. Consumption per ton of concentrate - KCN, 2 lb., CNBr, 0.5 lb. Time of Treatment, 80 - 100 hours; extraction of gold, 87 - 94 per cent.

Mineral Industry, Vol. XI, 1902 contains articles by Philip Argall on "Cyaniding Sulpho-Telluride Ores" and by W. A. Prichard and H. C. Hoover on "Treatment of Sulpho-Telluride Ores at Kalgoorlie". The former considers CNBr to be a cyanogen liberator and that the tellurides are attacked by the very active nascent cyanogen. The latter paper briefly describes the Diehl process as in operation at the Lake View mill and give the extractions as follows :- Oroya Brownhill, 92.3 per cent.; Lake View, 90 per cent.; Hannan's Star, 91 - 92 per cent.

In the following series of tests on South Kalgurli ore, assaying 10.8 dwt. Au per ton, which was ground in the pebble mill to pass a 200 mesh I.M.M. screen, the treatment conditions were kept constant and were as follows :-

Cyanide solution	0.15 per cent. KCN
CaO added during treatment	1 lb. per ton of ore
CaO added after treatment	2 lb. per ton of ore
Time of agitation with KCN	2 hours
CNBr added	1 lb. per ton of ore
Time of agitation with CNBr	1 hour.

The results of these tests are as follows :-

South Kalgurli Ore - Assay value, 10.8 dwt. Au per ton.

Test No.	Solution after treatment			Consumption of KCN, lb. per ton	Residue, dwt. Au per ton	Extraction, per cent.
	KCN, %	CaO, %	CNBr, %			
13	0.1355	0.0408	0.0013	0.29	3.3	69.44
14	0.1350	0.0228	0.0013	0.30	1.7	84.26
15	0.1335	0.0216	0.0013	0.33	1.75	83.79
16	0.1340	0.0204	0.0013	0.32	1.5	86.11
6 17	0.1310	0.0180	0.0013	0.38	1.3	87.96
18	0.1280	0.0108	0.0013	0.44	1.2	88.88
19	0.1390	0.0144	nil	0.22	1.65	84.72
20	0.1310	0.0144	trace	0.38	1.0	90.74
21	0.1360	0.0192	trace	0.28	1.3	87.96
22	0.1300	0.0072	nil	0.40	1.3	87.96
23	0.1300	0.0108	trace	0.40	1.3	87.96
24	0.1310	0.0192	trace	0.38	1.1	89.81
25	0.1300	0.0156	nil	0.40	1.05	90.28
26	0.1310	0.0132	trace	0.38	1.5	86.11
27	0.1360	0.0192	trace	0.28	2.0	81.48
28	0.1320	0.0228	trace	0.36	1.0	90.74
29	0.1320	0.0180	trace	0.36	1.1	89.81
30	0.1330	0.0180	nil	0.34	1.3	87.96

In this series of tests, the ore, of fair average grade, was not amalgamated before cyanidation and it was considered that possibly this might account for the erratic nature of the residue values and extractions, many of which were so nearly satisfactory as to encourage the belief that with further investigation, definite conditions might be determined which would enable extractions well over ninety per cent. to be obtained.

In order to determine the effect of amalgamation or non-amalgamation on the results obtained by cyanidation, a sample of the same ore from the South Kalgurli mine, assaying 10.8 dwt. gold per ton, was amalgamated during grinding in the pebble mills, the amalgam was removed by panning off the product in an amalgamated copper pan and the final amalgamation residue dried. This residue

assayed 8.0 dwt. gold per ton, showing that 25.92 per cent. of the gold in the original sample had been extracted by amalgamation.

In the series of tests on this ore, Tests were carried out under constant conditions similar to those obtaining in Tests 13 to 30, Tests 37 and 38 under the same conditions except the time of agitation with cyanogen bromide which was increased to two hours, while Test 39 was given four hours agitation with cyanide alone to furnish a comparison between the results obtainable with and without cyanogen bromide.

In the case of this sample of ore, amalgamation before cyanidation is apparently unnecessary as no improvement in extraction is obtained by the introduction of the preliminary amalgamation. At the same time, the introduction of amalgamation would be necessary in the treatment scheme to remove, before cyanidation, any gold not capable of being dissolved by the cyanide solution. The results of this series of tests are as follows :-

South Kalgurli Ore - Assay value, 10.8 dwt. Au per ton;
Amalgamation residue, 8.0 dwt. Au per ton.

Test No.	Soln. after treatment			KCN Consumption lb/ton	Residue dwt. Au per ton	Extraction, % (on amalgd. ore)	Extraction on orig. ore		
	KCN %	CaO %	CNBr %				By amalgn.	By cyanidn.	Total
31	0.121	0.0037	0.0014	0.58	1.55	80.62	25.92	59.73	85.65
32	0.136	0.0045	0.0014	0.28	1.3	83.75	25.92	62.04	87.96
33	0.140	0.0045	0.0014	0.20	1.1	86.25	25.92	63.71	89.63
34	0.138	0.0084	0.0014	0.24	1.35	83.12	25.92	61.58	87.50
35	0.136	0.0082	0.0014	0.28	1.25	84.37	25.92	62.51	88.43
36	0.140	0.0052	0.0014	0.20	1.2	85.00	25.92	62.97	88.89
37	0.143	0.0082	0.0013	0.14	1.05	86.87	25.92	64.35	90.27
38	0.135	0.0052	0.0013	0.30	1.25	84.37	25.92	62.50	88.42
39	0.147	0.0067	-	0.06	5.15	35.62	25.92	26.39	52.31

As the results of these tests are similar to those obtained in the previous series on the same ore, it is evident that the presence of coarse free gold is not the factor preventing a high percentage extraction from being obtained, and therefore other treatment factors must be varied to ascertain their effects on the cyanidation. A comparison of Test 39 with the other tests of the series shows clearly the accelerating action of cyanogen bromide, and that in a short period of agitation with plain cyanide solution, it is not possible to obtain more than a comparatively small percentage extraction of the gold.

A new sample of South Kalgurli ore was prepared for treatment by grinding in pebble mills, without amalgamation, to pass a 200 mesh screen, filtering and drying. This pebble mill product assayed 12.13 dwt. gold per ton. A number of series of tests was carried out on this product in which the time of agitation with cyanide and with cyanogen bromide and the concentration of the cyanide solution were varied, for the purpose of ascertaining the effect of increasing the concentration of the cyanide solution, and whether the time of treatment previously used was too short. All other treatment conditions were kept constant and similar to those obtaining in previous tests, viz.,

Agitation charge

200 gram ore, 200 c.c. KCN solution, 1 lb. CaO per ton of ore.

Cyanogen bromide addition 1 lb. per ton of ore
 CaO addition after treatment 2 lb. per ton of ore.

SERIES I.

This series was carried out under the conditions originally laid down by Mr. C. E. Blackett, to obtain results which would form a basis for comparison with the series of tests to be carried out under conditions suggested by the results of previous tests. The results are remarkably consistent and show that under the stated conditions 85 to 86 per cent. is the maximum extraction to be expected from this sample of ore.

Test No.	Soln. KCN, %	Time of agitn.		Soln. after treatment			Consumption of KCN, lb/ton	Residue dwt. Au per ton	Extraction, per cent.
		With KCN, hrs.	With CNBr, hrs.	KCN %	CaO %	CNBr %			
40	0.16	2	1	0.143	0.0067	trace	0.34	1.7	85.98
41	0.16	2	1	0.155	0.0171	trace	0.10	1.75	85.57
42	0.16	2	1	0.151	0.0134	trace	0.18	1.8	85.16
43	0.16	2	1	0.1495	0.0148	trace	0.21	1.8	85.16

SERIES II.Variation of time of agitation.

44	0.16	2.5	1.5	0.153	0.0171	0.0027	0.14	1.1	90.93
45	0.16	2.5	1.5	0.148	0.0089	0.0027	0.24	1.35	88.87
46	0.16	2.5	1.5	0.145	0.0117	0.0027	0.30	1.0	91.75

SERIES III.Variation of time of agitation.

47	0.16	3	1	0.146	0.0104	0.0033	0.28	1.5	87.63
48	0.16	3	1	0.148	0.0164	0.0033	0.24	1.95	83.51
49	0.16	3	1	0.142	0.0097	0.0033	0.36	2.1	82.64

Series II and III, in which time of agitation with KCN and with CNBr was varied, indicate that apparently no benefit is derived from an increase in the time of agitation with KCN alone, but that an increase in the time of agitation after the addition of CNBr increases the extraction by from 3.5 to 5 per cent. Therefore, other treatment conditions remaining constant, an increase in the time of agitation after addition of CNBr improves the extraction, although, from theoretical considerations, nothing will be gained by prolonging this period beyond that at which the whole of the CNBr has been destroyed. Consequently, it becomes necessary to determine the period of agitation with CNBr which will yield the best results.

In the next two series of tests, the effect of increases in the concentration of the cyanide solution was determined, all other treatment conditions being maintained constant as originally suggested by Mr. Blackett.

SERIES IV.Increased concentration of cyanide solution.

Test No.	Soln. KCN %	Time of agitn.		Soln. after treatment			Consumption of KCN, lb/ton	Residue dwt. Au per ton	Extraction per cent.
		With KCN, hrs.	With CNBr, hrs.	KCN %	CaO %	CNBr %			
50	0.203	2	1	0.194	0.0112	0.0091	0.18	1.7	85.98
51	0.203	2	1	0.190	0.0164	0.0121	0.26	1.9	84.34
52	0.203	2	1	0.184	0.0141	0.0162	0.38	1.4	88.46

SERIES V.Increased concentration of cyanide solution.

53	0.25	2	1	0.231	0.0156	0.0121	0.38	2.55	78.98
54	0.25	2	1	0.234	0.0149	0.0148	0.32	2.2	81.86
55	0.25	2	1	0.231	0.0116	0.0202	0.38	2.1	82.68

These two series appear to lead to the conclusion that increasing the concentration of the cyanide solution increases the grade of the residues, or decreases the extraction, although the average extraction is slightly higher in Series IV than in Series I. Therefore, apparently, cyanide solutions of greater concentration than 0.16 per cent. KCN are disadvantageous, and it may be possible that even weaker cyanide solutions may be equally as effective as 0.16 per cent. solutions.

It is not advisable, if such can be avoided, to increase the quantity of cyanogen bromide used above 1 lb. per ton of ore, on account of the cost of this reagent, and therefore it is necessary to determine the effect of increased time of agitation with cyanide or cyanogen bromide, or with both, and of cyanide solutions of less concentration than 0.16 per cent. KCN.

The consumption of cyanide during the treatment is in nearly all cases very low, and apparently none of the treatment conditions which has been varied up to the present seriously affects this item.

In order to determine the effect of further increases in the time of treatment of this ore, both with cyanide and with cyanogen bromide, the following series of tests has been carried out on the same sample of ore, assaying 12.13 dwt. gold per ton, in which the time of agitation was increased to three hours with cyanide solution, followed by two hours' agitation after addition of 1 lb. CNBr per ton of ore. Other conditions of treatment have been similar to the conditions obtaining in previous tests, the cyanide solution assaying 0.148 per cent. KCN.

SERIES VI.

South Kalgurli Ore - Assay value. 12.13 dwt. gold per ton.

Test No.	Soln. KCN %	Time of agitin.		Soln. after treatment			Consumption of KCN, lb/ton	Residue, dwt. Au per ton	Extraction, per cent.
		With KCN, hrs.	With CNBr, hrs.	KCN, %	CaO, %	CNBr, %			
56	0.148	3	2	0.125	0.0059	0.0189	0.46	1.4	88.46
57	0.148	3	2	0.121	0.0052	0.0202	0.54	1.0	91.75
58	0.148	3	2	0.1215	0.0052	0.0175	0.53	1.0	91.75

These tests indicate that it may be possible to obtain higher percentage extractions by increasing the time of agitation with both cyanide and cyanogen bromide, although Series II and III indicated that the time of agitation after addition of cyanogen bromide was more important than the time of agitation with cyanide, two hours' treatment with cyanide being apparently as effective as three hours' agitation. It appears also that this increase in the agitation times also results in increased consumption of cyanide, although this is still comparatively small.

The supply of this sample of ore having been exhausted, a new sample of South Kalgurli ore was prepared as before, but was found to assay only 5.9 dwt. gold per ton. On this sample a number of series of tests have been carried out with weaker cyanide solution - 0.1 per cent. KCN - and different times of agitation.

SERIES VII.

South Kalgurli Ore - Assay value, 5.9 dwt. gold per ton.

Test No.	Soln. KCN %	Time of agitin.		Soln. after treatment			Consumption of KCN, lb/ton	Residue, dwt. Au per ton	Extraction, per cent.
		With KCN, hrs.	With CNBr, hrs.	KCN, %	CaO, %	CNBr, %			
59	0.106	2	2	0.087	0.0134	0.0040	0.38	1.3	77.97
60	0.106	2	2	0.084	0.0178	0.0027	0.44	0.8	86.44
61	0.106	2	2	0.083	0.0158	0.0040	0.46	1.1	81.36

SERIES VIII.

62	0.106	3	2	0.100	0.0149	0.0040	0.12	0.8	86.44
63	0.106	3	2	0.102	0.0171	0.0067	0.08	0.7	88.13
64	0.106	3	2	0.100	0.0208	0.0054	0.12	0.6	89.83

SERIES IX.

65	0.104	4	2	0.095	0.0119	0.0189	0.18	1.4	76.27
66	0.104	4	2	0.0955	0.0126	0.0204	0.17	2.0	66.10
67	0.104	4	2	0.092	0.0082	0.0216	0.24	0.7	88.13

SERIES X.

68	0.105	2	1	0.1045	0.0253	0.0067	0.01	1.0	83.05
69	0.105	2	1	0.105	0.0253	0.0052	0.00	1.0	83.05
70	0.105	2	1	0.105	0.0297	0.0091	0.00	1.1	81.36

These series show that the maximum agitation periods necessary for this ore under these conditions are three hours with cyanide solution and two hours after addition of cyanogen bromide, and that increasing the time of agitation with cyanide solution beyond three hours lowers the extraction.

Although the consumption of cyanide is always low in a properly conducted test, it was not ~~to be~~ expected that it would become practically nil in Series X. This low cyanide consumption can, however, be explained by taking into account the cyanide content of the added cyanogen bromide which should, by reason of its process of production, always contain a certain amount of free cyanide. In these tests the cyanogen bromide solution used contained 2.39 per cent. CNBr, and therefore 4.2 c.c. of this solution contained 0.1 gram KCN (equivalent to 1 lb. per ton of ore on a 200 gram charge). After neutralising 4.2 c.c. of this stock solution with lime water and titrating with standard silver nitrate solution, it was found to contain 0.022 gram KCN as free cyanide. Addition of this quantity of free cyanide to the 200 c.c. of cyanide solution used in each test increases its free cyanide content by 0.011 per cent., so that the actual free cyanide available in these tests was $0.105 + 0.011 = 0.116$ per cent. The consumption of cyanide has been calculated only on the basis of the cyanide solution without taking into account the cyanide introduced in the cyanogen bromide stock solution, and therefore the actual consumption of cyanide should be 0.22 lb. per ton more than that calculated from the concentration of the cyanide solution alone. Therefore, in this series of tests in which the consumption of cyanide is apparently nil, it is actually 0.23, 0.22 and 0.22 lb. per ton in the three tests. That this is a feasible explanation of this apparently peculiar fact is confirmed by the results of the determination of free cyanide in the filtered solution from the treatment of the ore in some tests before addition of the lime necessary for neutralisation, when an increase in the free cyanide content of the solution, of approximately 0.01 per cent., was found to take place after neutralisation. This explanation will account for the very low cyanide consumption in many of the tests. At the same time, in practice, it is customary to base the consumption of cyanide on the ~~the~~ difference between the free cyanide content of the solution before and after treatment, so that on this basis the consumption would be as stated in the results of the tests.

On account of the unsatisfactory nature of the results of the tests of Series IX, these tests were repeated on the same ore and under the same conditions, with the trifling exception that the strength of the cyanide solution was 0.1 per cent. instead of 0.104 per cent.

SERIES XI.

South Kalgurli Ore) Assay value, 5.9 dwt. gold per ton.

Test No.	Soln. KCN, %	Time of agitn.		Soln. after treatment			Consumption of KCN, lb/ton	Residue, dwt. Au per ton	Extraction, per cent.
		With KCN, hrs.	With CNBr, hrs.	KCN, %	CaO, %	CNBr, %			
71	0.1	4	2	0.0985	0.0186	0.0121	0.03	1.0	83.05
72	0.1	4	2	0.100	0.0172	0.0121	0.00	1.2	79.66
73	0.1	4	2	0.099	0.0268	0.0121	0.02	1.3	77.97

These series of tests, with weak cyanide solution, show that it is a disadvantage to prolong the time of agitation with cyanide solution beyond three hours, and that the extraction of gold is less with a 0.1 per cent. cyanide solution than with a 0.15 per cent. solution.

Previous tests in which one pound of cyanogen bromide per ton of ore was used have, on account of the presence of cyanogen bromide in the solution after completion of the test, led to the conclusion that it might be possible to reduce the cyanogen bromide addition to 0.75 lb. per ton of ore without harmful effect. Consequently, four series of tests were carried out with the diminished quantity of cyanogen bromide, but, in every case, the residues have been of high grade, although it is possible that the weaker cyanide solution may have also contributed to this result.

On account of the low grade of the sample of ore used in the last five series of tests it was considered advisable to discontinue treatment of this sample for the time being, and consequently a new sample of Boulder Perseverance ore was prepared in the usual way for treatment. This sample assayed 11.2 dwt. gold per ton. Previous tests having shown the advisability of agitation with cyanogen bromide for at least two hours, four series of tests have been carried out on this ore in which three and four hour periods of agitation with cyanide have been adopted, while 1 lb. and 0.75 lb. additions of cyanogen bromide per ton of ore have been made. In all these tests all other treatment conditions have remained constant.

SERIES XII.

1 lb. CNBr per ton of ore.

Test No.	Soln. KCN, %	Time of agitin.		Soln. after treatment			Consumption of KCN, lb/ton	Residue, dwt. Au per ton	Extraction, per cent.
		With KCN, hrs.	With CNBr, hrs.	KCN, %	CaO, %	CNBr, %			
74	0.1	3	2	0.094	0.0141	0.0162	0.12	3.7	66.96
75	0.1	3	2	0.094	0.0097	0.0189	0.12	3.8	66.07
76	0.1	3	2	0.095	0.0089	0.0256	0.10	3.0	73.21

SERIES XIII.

1 lb. CNBr per ton of ore.

77	0.1	4	2	0.095	0.0171	0.0108	0.10	3.1	72.32
78	0.1	4	2	0.095	0.0104	0.0108	0.10	3.0	73.21
79	0.1	4	2	0.094	0.0149	0.0175	0.12	2.8	75.00

SERIES XIV.

0.75 lb. CNBr per ton of ore.

80	0.1	3	2	0.091	0.0231	0.0168	0.18	4.2	62.50
81	0.1	3	2	0.0895	0.0164	0.0168	0.21	4.15	62.95
82	0.1	3	2	0.090	0.0112	0.0168	0.20	4.2	62.50

SERIES XV.

0.75 lb. CNBr per ton of ore.

83	0.1	4	2	0.095	0.0149	0.0114	0.10	3.2	71.43
84	0.1	4	2	0.095	0.0149	0.0141	0.10	3.4	69.64
85	0.1	4	2	0.095	0.0245	0.0131	0.10	7.7	40.18

These series showed that a reduction in the quantity of cyanogen bromide used resulted in lower extraction which was slightly improved by increasing the time of agitation with cyanide from three to four hours.

The unsatisfactory nature of the results of the tests of the last four series led to their repetition under exactly similar conditions on a new sample of Boulder Perseverance ore, amalgamated during grinding, as it was considered that possibly this ore contained some gold too coarse for ready dissolution. This sample of ore assayed 14.27 dwt. gold per ton before, and 11.47 dwt. gold per ton after amalgamation, representing an extraction by amalgamation of 19.62 per cent. of the gold.

SERIES XVI.

1 lb. CNBr per ton of ore.

Test No.	Soln KCN, %	Agit. Time		Soln. after treatment			KCN Consumption, lb/ton	Residue dwt. Au per ton	Extraction on amalgd ore	Extraction on original ore, per cent.		
		With KCN hrs.	With CNBr hrs.	KCN %	CaO %	CNBr %				By amalg.	By cyan- idn.	Total
86	0.1	3	2	0.0910	0.01930	0.0108	0.18	3.35	70.79	19.62	56.90	76.52
87	0.1	3	2	0.0940	0.02150	0.0094	0.12	3.95	65.56	19.62	52.70	72.32
88	0.1	3	2	0.0900	0.02150	0.0094	0.20	3.75	67.30	19.62	54.10	73.72

SERIES XVII.

1 lb. CNBr per ton of ore.

89	0.1	4	2	0.0870	0.01640	0.0135	0.26	3.8	66.87	19.62	53.75	73.37
90	0.1	4	2	0.0860	0.01410	0.0189	0.28	4.3	62.51	19.62	50.25	69.87
91	0.1	4	2	0.0880	0.01710	0.0121	0.24	3.95	65.56	19.62	52.70	72.32

SERIES XVIII.

0.75 lb. CNBr per ton of ore.

92	0.1	3	2	0.0880	0.01340	0.0054	0.24	5.0	56.41	19.62	45.34	64.96
93	0.1	3	2	0.0840	0.02680	0.0040	0.32	5.05	55.97	19.62	44.99	64.61
94	0.1	3	2	0.0850	0.01780	0.0040	0.30	5.1	55.53	19.62	44.64	64.26

SERIES XIX.

0.75 lb. CNBr per ton of ore.

95	0.1	4	2	0.0880	0.01710	0.0081	0.24	5.1	55.53	19.62	44.64	64.26
96	0.1	4	2	0.0840	0.02160	0.0040	0.32	5.2	54.66	19.62	43.94	63.56
97	0.1	4	2	0.0870	0.01710	0.0040	0.26	5.7	50.30	19.62	40.43	60.05

These duplicate series lead to the conclusions that for this particular ore

- (1) Amalgamation before cyanidation is not necessary.
- (2) A 0.1 per cent. cyanide solution is much less efficient than a 0.15 per cent. solution, the latter of which appears to give the best results of all the solutions used in the whole series of tests.
- (3) The minimum effective quantity of cyanogen bromide is 1 lb. per ton of ore.
- (4) Apparently the best times of agitation are three hours with cyanide solution and two hours after addition of cyanogen bromide.

(5) Consumption of cyanide is always low.

For the purpose of determining the extraction obtainable by this method of treatment of ore crushed to different sizes, a sample of South Kalgurli ball mill product was graded by screening through 60 mesh, 100 mesh, and 150 mesh I.M.M. screens. No residue remained on the 60 mesh screen and therefore three products were obtained, viz., -60 + 100 mesh, - 100 + 150 mesh, and - 150 mesh. Each of these sizes was then bromocyanided with and without the addition of lime during the preliminary agitation with cyanide solution, and, concurrently, a check test was run on the same size material for the full time - three hours - with plain cyanide solution of the same concentration as that used in the bromocyanidation tests, for the purpose of determining the extraction obtainable by plain cyanide under exactly the same conditions as the bromocyanide tests, except the addition of cyanogen bromide.

The conditions under which these tests were carried out and the results obtained are shown in the following tabulation which shows that under those conditions which have previously been shown to yield satisfactory extractions on minus 200 mesh material a high percentage extraction or a low grade residue is not obtainable on material coarser than minus 150 mesh, but that economically satisfactory residues can be obtained from minus 150 mesh material after two hours' treatment with cyanide alone, followed by treatment with cyanogen bromide for one hour. Since this ore had been crushed dry, and had had no washing with water as was the case during the grinding of the ore for previous tests, an addition of lime equivalent to 5 lb. per ton of ore was made to the agitation charge before agitation with cyanide in order to neutralise the possible effect of cyanicides in the ore on the cyanide. In consequence the consumption of cyanide in all tests was comparatively low. A further addition of lime equivalent to 5 lb. per ton of ore was made after completion of the treatment with cyanide and cyanogen bromide.

South Kalgurli Ball Mill Product - Graded.

Test No. Ore, weight, gram Soln. { KCN, Vol., c.c. CaO added, lb/ton CNBr added, lb/ton Hrs. agtn. { KCN CNBr	- 60 + 100 mesh			- 100 + 150 mesh			- 150 mesh											
	Without CaO		With CaO	Without CaO		With CaO	Without CaO		With CaO									
	KCN alone	KCN+CNBr	KCN	KCN	KCN+CNBr	KCN alone	KCN+CNBr	KCN alone	KCN+CNBr									
98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	
200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	
0.146	0.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.146	0.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.1460.1460.1460.146	0.1460.1460.1460.146	
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
0.126	0.114	0.1120.1360.133	0.133	0.133	0.133	0.1240.1110.111	0.1110.1110.1110.111	0.1250.1220.121	0.1250.1220.121	0.1250.1220.121	0.1250.1220.121	0.1140.1060.101	0.1060.1060.101	0.1140.1060.101	0.1120.115	0.115	0.113	0.113
0.080	0.038	0.0440.0750.098	0.098	0.102	0.102	0.0440.0260.046	0.0260.046	0.0840.1130.110	0.0840.1130.110	0.0840.1130.110	0.0840.1130.110	0.0410.0260.037	0.0260.037	0.0410.0260.037	0.0510.104	0.104	0.101	0.101
-	0.0005.0005	-	0.00020.0002	-	-	0.00080.0008	-	-	0.00030.0003	-	-	-	0.0010.005	-	0.00020.0002	-	0.00020.0002	0.0002
0.4	0.64	0.68	0.20	0.26	0.26	0.44	0.70	0.70	0.42	0.48	0.50	0.64	0.80	0.90	0.68	0.62	0.66	
Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	Head per ton	
7.2	7.2	7.2	7.2	7.2	7.2	8.4	8.4	8.4	8.4	8.4	8.4	8.0	8.0	8.0	8.0	8.0	8.0	
Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	Residue value , dwt. Au per ton	
5.6	4.8	2.4	4.0	4.0	3.4	4.1	2.15	2.15	3.6	3.8	3.75	3.0	2.85	3.2	3.0	0.95	1.1	
Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	Extraction, per cent.	
22.2	33.3	66.7	44.4	44.4	52.8	51.2	74.4	74.4	57.1	54.7	55.4	62.5	64.4	60.0	62.5	86.1	86.2	

For the purpose of determining the times of agitation with cyanide and with cyanogen bromide which would yield the best extractions and would therefore enable the best time of treatment to be determined, series of tests have been carried out on Boulder Perseverance ore ground wet in the pebble mill to pass a 200 mesh I.M.M. screen. This ore was not amalgamated before cyanidation. The only treatment factor that has been varied in these series of tests has been time of agitation, either with cyanide or cyanogen bromide, all other factors remaining constant. Three tests have been run under each of the separate time conditions, in one of which no cyanogen bromide was added, and in the other two tests cyanogen bromide was added in the proportion of one pound per ton of ore. In the case of the tests with cyanide alone, the total time of agitation was the same as the total time of agitation in the other two tests with both cyanide and cyanogen bromide, these tests being run to enable a comparison to be made between the results obtainable with cyanide alone and with cyanide and cyanogen bromide under otherwise similar conditions. Previous tests had indicated that it was inadvisable to add lime during the period of agitation with cyanide alone, that the addition of 2 lb. of lime per ton of ore was sufficient after agitation with cyanogen bromide, and that a solution concentration of approximately 0.15 per cent. KCN was the most suitable cyanide solution. Therefore these conditions were adhered to in this series of tests.

The results of these tests show that in all cases it was impossible to obtain more than twenty five per cent. extraction of the gold with cyanide alone, whereas with the addition of cyanogen bromide the maximum extraction obtained was 92.8 per cent. after three hours' agitation with cyanide alone and an additional two hours' agitation after addition of cyanogen bromide. In every case where cyanogen bromide was used, it was present in small quantity after completion of the test, while the consumption of cyanide which was very low in the tests with cyanide alone, varied up to 1.14 lb. per ton in the tests with cyanogen bromide. In all the cyanogen bromide tests, the whole of that reagent was added at once.

These tests apparently show that on this particular ore the time of agitation does not materially affect the extraction, although the best results were obtained after three hours' agitation with cyanide and two hours' agitation with cyanogen bromide. The difference between the results obtained under these conditions of time and those obtained under the other times of agitation is so small that the extra gold extracted might not, in practice, compensate for the extra power utilised in prolonging the agitation time, in addition to which, an extension of time of agitation reduces the treatment capacity of a plant of a given size to an extent which may not be commensurate with the additional extraction of gold.

The results of these tests are shown in the following tabulation.

EFFECT OF VARIATION OF TIME OF AGITATION.

Boulder Perseverance Ore - Assay value, 11.2 dwt. gold per ton.

Test No. Ore, weight, Gram Cyanide solution Cyanogen bromide added, Time of agitation, hrs. CaO added after treatment Solution after treatment Consumption of KCN, lb. per ton Head Value , dwt. Au per ton Residue Value , dwt. Au per ton Extraction, per cent.	Three hours agitation		Four hours agitation		Four hours agitation		Four hours agitation		Five hours agitation		Five hours agitation	
	KCN alone	KCN + CNBr	KCN alone	KCN + CNBr	KCN alone	KCN + CNBr	KCN alone	KCN + CNBr	KCN alone	KCN + CNBr	KCN alone	KCN + CNBr
116	200	200	200	200	200	200	200	200	200	200	200	200
117	200	200	200	200	200	200	200	200	200	200	200	200
118	200	200	200	200	200	200	200	200	200	200	200	200
119	200	200	200	200	200	200	200	200	200	200	200	200
120	200	200	200	200	200	200	200	200	200	200	200	200
121	200	200	200	200	200	200	200	200	200	200	200	200
122	200	200	200	200	200	200	200	200	200	200	200	200
123	200	200	200	200	200	200	200	200	200	200	200	200
124	200	200	200	200	200	200	200	200	200	200	200	200
125	200	200	200	200	200	200	200	200	200	200	200	200
126	200	200	200	200	200	200	200	200	200	200	200	200
127	200	200	200	200	200	200	200	200	200	200	200	200
	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146
	-	1	1	1	1	1	1	1	1	1	1	1
	3	2	2	3	3	4	2	2	5	3	2	3
	2	2	2	1	2	2	2	2	2	2	2	2
	0.128	0.101	0.102	0.131	0.110	0.108	0.129	0.107	0.127	0.108	0.095	0.095
	0.009	0.007	0.008	0.013	0.007	0.010	0.010	0.026	0.012	0.009	0.016	0.016
	-	0.0040	0.0030	-	0.0030	0.0030	-	0.0015	-	0.0068	0.0042	0.0042
	0.36	0.90	0.88	0.30	0.72	0.76	0.30	0.74	0.34	0.72	1.04	1.04
	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
	9.9	1.2	0.9	9.4	2.0	1.0	9.3	1.6	8.4	0.8	0.8	0.8
	11.6	89.3	91.9	16.1	82.1	91.1	16.9	85.7	25.0	92.8	92.8	92.8

In order to determine the effect of adding cyanogen bromide at intervals, further series of tests have been carried out under similar conditions to those obtaining in the preceding series, except that the cyanogen bromide has been added in two equal portions in each test at equal intervals of time. The results of these series appear to indicate that no advantage is gained by adding the cyanogen bromide at intervals, since equally good extractions were obtained in the previous series when the cyanogen bromide was added all at once. When the period of agitation with cyanogen bromide was one hour, the cyanogen bromide was added at half-hourly intervals, i.e., at the completion of the period of agitation with cyanide alone, and half an hour later; when the period of agitation with cyanogen bromide was two hours, the cyanogen bromide was added at hourly intervals, i.e., at the completion of the period of agitation with cyanide alone, and one hour later.

The results of these series are shown in the following tabulation.

EFFECT OF ADDITION OF CYANOGEN BROMIDE IN TWO EQUAL PORTIONS.

	Three hours' agitation		Four hours' agitation		Four hours' agitation		Five hours' agitation	
	128	129	130	131	132	133	134	135
Test No.	128	129	130	131	132	133	134	135
Ore, wt., gm.	200	200	200	200	200	200	200	200
Soln., (Vol., c.c.)	200	200	200	200	200	200	200	200
(KCN, %)	0.144	0.144	0.160	0.160	0.144	0.144	0.144	0.144
Cyanogen bromide added, lb. ton	1	1	1	1	1	1	1	1
Agitn. (KCN time, hrs.)	2	2	3	3	2	2	3	3
(CNBr treatment, lb. per ton)	1	1	1	1	2	2	2	2
CaO added after treatment, lb. per ton	2	2	2	2	2	2	2	2
Soln. (KCN, %)	0.103	0.102	0.131	0.132	0.100	0.100	0.098	0.096
after (CaO, %)	0.018	0.016	0.007	0.006	0.018	0.017	0.016	0.017
treatment (CNBr, %)	0.0057	0.0079	0.0052	0.0042	0.0052	0.0047	0.0037	0.0047
Consumption of KCN, lb/ton	0.82	0.84	0.58	0.56	0.88	0.88	0.92	0.96
Head Value, dwt. Au per ton	11.42	11.42	11.47	11.47	11.42	11.42	11.42	11.42
Residue Value, dwt. Au per ton	1.5	1.6	2.0	1.4	1.0	1.05	1.3	1.0
Extraction, per cent.	86.6	85.7	82.56	87.79	91.1	90.6	88.4	91.1

For the purpose of providing a comparison between the results obtainable by the bromocyanidation of raw ore and amalgamated ore, and to show also the effect of agitation with cyanide alone, as well as the increased extraction resulting from a short period of agitation after the addition of one pound of cyanogen bromide per ton of ore, two series of tests were carried out on Boulder Perseverance ore, ground wet in pebble mills to pass a 200 mesh screen, the maximum total time of treatment in each series being three hours. In order to indicate the extent to which solution of the gold had taken place up to the addition of the cyanogen bromide, a test was run concurrently in each series in which agitation with cyanide solution was stopped after two hours. These two tests, Nos. 136 and 139, show that in two hours the percentage of the gold dissolved is very small and when considered in conjunction with the similar tests, Nos. 138 and 141, in which the ore was subjected to a subsequent treatment of one hour after addition of cyanogen bromide, show the great accelerating action of cyanogen bromide on the solution of the gold. The results of the two series of tests, which are intended only to show the advisability of amalgamation of this ore before bromocyanidation, indicate that a greater total extraction may be expected by the introduction of amalgamation before cyanidation. In the case of Kalgoorlie ores, which are always liable to contain a certain amount of coarse free gold which is only extremely slowly dissolved by cyanide solution or by mixed cyanide and cyanogen bromide solution, it is evident that the introduction of amalgamation before cyanidation is essential.

Amalgamation was carried out by adding mercury to the grinding charges in the pebble mills, which were afterwards panned in a copper amalgamating pan to recover amalgam and mercury. The extraction obtained by amalgamation was 11.9 per cent. On a mill scale, amalgamation in tube mills which are commonly used for the fine grinding would not be feasible on account of the inefficiency of the tube mill as an amalgamator and the difficulty of completely cleaning up the amalgam from the mills. Amalgamation would therefore in practice be carried out by allowing the tube mill slime to flow over amalgamated copper plates or by completing the fine grinding in grinding pans with mercury.

The results of these comparative tests are shown in the following table.

EFFECT OF AMALGAMATION BEFORE BROMOCYANIDATION.

Boulder Perseverance Ore.

Before amalgamation 16.8 dwt. gold per ton
 After amalgamation 14.8 dwt. gold per ton
 Extraction by amalgamation - 11.9 per cent.

	Amalgamated ore			Non-amalgamated ore		
	136	137	138	139	140	141
Test No.	136	137	138	139	140	141
Ore, weight, gram	200	200	200	200	200	200
Barren solution, (volume c.c.)	200	200	200	200	200	200
(KCN, %)	0.153	0.153	0.153	0.153	0.153	0.153
CNBr added, lb. per ton	0	0	1	0	0	1
Agitation time, hrs (KCN)	2	3	2	2	3	2
(CNBr)	-	-	1	-	-	1
CaO added after treatment, lb. per ton	2	2	2	2	2	2
Pregnant solution, (KCN, %)	0.130	0.127	0.115	0.120	0.113	0.110
(CNBr, %)	0	-	0.0031	-	-	0.0031
(CaO, %)	0.003	0.003	0.007	0.002	0.001	0.003
KCN Consumption, lb. per ton	0.46	0.52	0.76	0.66	0.80	1.06
Head Value, dwt. Au per ton	14.8	14.8	14.8	16.8	16.8	16.8
Residue Value, Au, dwt. per ton	12.4	11.6	2.9	15.2	13.6	3.6
Extraction, per cent.	16.21	21.62	80.40	9.52	19.05	78.57

Although the consumption of cyanide in all these tests is comparatively high, this is probably due to non-addition of lime during the agitation period with cyanide alone. The consumption of cyanide is also higher on non-amalgamated ore than on amalgamated ore.

The total extractions by amalgamation and cyanidation are shown in the following table in comparison with the extractions by cyanidation alone.

EXTRactions BY AMALGAMATION AND CYANIDATION.

Test No.	By Amalgamation per cent.	By Cyanidation per cent.	Total per cent.
136	11.9	14.28	26.18
137	11.9	19.05	30.95
138	11.9	70.83	82.73
139	-	9.52	9.52
140	-	19.05	19.05
141	-	78.57	78.57

As nearly all the previous tests had been carried out on ore from the eastern series of lodes, and as there are certain differences in the characteristics of the ores from the eastern and western series of lodes, it was considered advisable to determine the effect of similar methods of treatment on the ores from the latter series. Therefore a sample of ore from the Golden Horseshoe Estates was procured for testing purposes through the courtesy of Mr. J. W. Sutherland, General Manager of the Company.

The preliminary treatment of this ore in preparation for cyanidation was similar to that adopted in the case of the ores previously tested, viz., crushing dry to pass a 16 mesh I.M.M. screen and grinding wet in pebble mills to pass a 200 mesh I.M.M. screen, the product being filtered under pressure and allowed to dry without the application of artificial heating.

As, in previous tests, it had been found possible to secure extractions of at least 90 per cent. of the gold by varying the total time of treatment from 3 to 5 hours, comparative tests were carried out on this ore, without amalgamation, by agitation, in one case, for two hours with plain cyanide solution and a further one hour after addition of one pound of cyanogen bromide per ton of ore, and in the other case, for three hours with plain cyanide solution and a further two hours after addition of one pound of cyanogen bromide per ton of ore. At the same time, comparative tests were carried out by agitating for the full periods of three and five hours, respectively, with plain cyanide solution under similar conditions to those obtaining in the bromocyanidation tests except for the cyanogen bromide addition.

In these two series of tests no lime was added to the charges at the commencement of the cyanidation period since it is recognised that the best results are obtained from bromocyanidation in a solution containing a minimum of alkali.

These two series showed that on this particular ore high percentage extractions, with comparatively low grade residues, are obtainable under both time conditions and that practically no benefit is in this case derived by prolonging the treatment period beyond three hours. This ore appears to be peculiarly amenable to cyanidation as comparatively high percentage extractions were obtained by the treatment with cyanide alone.

In all the bromocyanidation tests the consumption of cyanide was comparatively high, which was considered to be due possibly to the omission of lime from the treatment charge.

The results of these two series of tests are shown in the following table.

BROMOCYANIDATION OF GOLDEN HORSESHOE ORE.

Test No.	142	143	144	145	146	147
Ore weight, gram	200	200	200	200	200	200
Barren (Volume, c.c.)	200	200	200	200	200	200
Solution (KCN, per cent.)	0.155	0.155	0.155	0.155	0.155	0.155
CNBr added, lb. per ton	-	1	1	-	1	1
Agitation (With KCN time, hours)	3	2	2	5	3	3
(With CNBr time, hours)	-	1	1	-	2	2
CaO added after agitation lb. per ton	2	2	2	2	2	2
Pregnant (KCN, per cent.)	0.128	0.112	0.104	0.114	0.114	0.107
Solution (CNBr, per cent.)	-	0.0034	0.0036	-	0.0026	0.0021
(CaO, per cent.)	0.006	0.007	0.010	0.004	0.008	0.002
KCN Consumption, lb. per ton	0.54	0.86	1.02	0.82	0.82	0.96
Head Value, dwt. Au per ton	15.2	15.2	15.2	15.2	15.2	15.2
Residue Value, dwt. Au per ton	10.9	1.2	1.0	9.1	1.1	0.9
Extraction, per cent.	28.29	92.10	93.42	40.13	92.76	94.08

As the solution, after the completion of bromocyanidation tests, invariably shows the presence of cyanogen bromide by the method of determination previously described, and as acid solutions of ferricyanide will also liberate iodine from potassium iodide, it was considered that possibly ferricyanides were being reported as cyanogen bromide. In order to enable a conclusion to be reached on this point, the solutions from Tests 142 and 145 in which no cyanogen bromide was used, were tested in the usual way for compounds capable of liberating iodine from potassium iodide in acetic acid solution, but the results in each case were negative. Therefore it is reasonable to conclude that cyanogen bromide is actually present in the pregnant solutions from the bromocyanidation tests, although it has been generally considered that in a cyanide solution cyanogen bromide is completely destroyed in from one to two hours.

To determine the effect on the cyanide consumption and on the extraction of gold of an initial addition of lime, duplicates of Tests 142 - 147 were carried out, in which 2 lb. CaO per ton of ore were added to the ore charge at the commencement of agitation. While the effect of this addition of lime was to diminish the consumption of cyanide, it also very seriously diminished the percentage extraction in the bromocyanidation tests, probably owing to rapid destruction of cyanogen bromide by free lime, although in the tests with plain cyanide solution, the extraction, as was expected, increased appreciably. These results are shown in the following table.

EFFECT OF INITIAL ADDITION OF LIME.

GOLDEN HORSESHOE ORE.

Test No.	148	149	150	151	152	153
Ore, weight, gram	200	200	200	200	200	200
Barren (Volume, c.c.	200	200	200	200	200	200
Solution (KCN, per cent.	0.151	0.151	0.151	0.151	0.151	0.151
CNBr added, lb. per ton	-	1	1	-	1	1
Agitation (With KCN	3	2	2	5	3	3
time, hours (With CNBr	-	1	1	-	2	2
CaO additions (Initial	2	2	2	2	2	2
lb. per ton (Final	2	2	2	2	2	2
Pregnant (KCN, per cent.	0.133	0.129	0.128	0.129	0.122	0.116
Solution (CNBr, per cent.	-	0.0074	0.0148	-	0.0042	0.0037
(CaO, per cent.	0.035	0.018	0.022	0.018	0.018	0.015
KCN Consumption, lb. per ton	0.36	0.44	0.46	0.44	0.58	0.70
Head Value, dwt. Au per ton	15.2	15.2	15.2	15.2	15.2	15.2
Residue Value, dwt. Au per ton	8.3	4.5	2.9	8.6	3.6	2.2
Extraction, per cent.	45.4	70.4	80.9	43.4	76.3	85.5

Since this ore yielded, in short periods of agitation, much higher percentage extractions by plain cyanide solution than had ~~the case with~~ other ores, a determination was made of the effect of prolonged agitation with plain cyanide solution after addition of lime. These tests showed that, apparently, a maximum extraction was reached at forty eight hours under the treatment conditions adopted. The results of these tests are shown in the following table.

EFFECT OF PROLONGED AGITATION WITH CYANIDE SOLUTION.

GOLDEN HORSESHOE ORE.

Test No.	154	155	156
Ore, weight, gram	200	200	200
Barren (Volume, c.c.	200	200	200
Solution (KCN, per cent.	0.151	0.151	0.151
CaO addition, lb. per ton	2	2	2
Agitation time, hours	42	48	54
Pregnant (KCN, per cent.	0.130	0.119	0.119
Solution (CaO, per cent.	0.007	0.007	0.007
KCN Consumption, lb. per ton	0.42	0.64	0.64
CaO Consumption, lb. per ton	1.86	1.86	1.86
Head Value, dwt. Au per ton	15.2	15.2	15.2
Residue Value, dwt. Au per ton	5.6	5.2	5.2
Extraction, per cent.	63.16	65.79	65.79

In mill practice it may not always be possible to transfer an agitation charge to the filters within a short time of the completion of treatment with cyanide and cyanogen bromide and after the final addition of lime, but it may be necessary to hold the charge in the agitation vat for some time. An opinion appears to be held that holding a charge under agitation in this way is a disadvantage and that by so doing, a certain amount of reprecipitation of the gold from solution takes place. As such a procedure may often be necessary, it is imperative that the effect of such treatment should be determined. For this purpose a charge of Golden Horseshoe ore was agitated for three hours with plain cyanide solution, followed by a further two hours after the addition of cyanogen bromide. After five hours' treatment, lime was added equivalent to 2 lb. per ton of ore, the charge was agitated for a few minutes and sampled. Agitation was then continued and the charge sampled at half-hourly intervals, the final sample, taken at 6.5 hours consisting of the residue of the charge.



The pregnant solution and the residue from each of these samples were assayed, but the results are inconclusive and require further confirmation. The result of this test appears to indicate that holding the charge under agitation for one hour after addition of lime has no harmful effect, but that any further delay in filtering the charge results in an increase in the grade of the residues and a consequent lower percentage extraction. At the same time, it is possible that the method of dip-sampling the charge may be inaccurate. Therefore, further confirmation of the results is necessary.

The conditions and the results of this test are shown below.

EFFECT OF CONTINUED AGITATION AFTER FINAL ADDITION OF LIME.

GOLDEN HORSESHOE ORE.

Test 157.

Treatment Conditions :-

Ore, weight, gram	800
Solution { Volume, c.c.	800
{ KCN, per cent.	0.151
CNBr added, lb. per ton	1
Agitation time, hours (With KCN	3
(With CNBr	2
CaO addition, lb. per ton	2

Results :-

Time, hours	5	5.5	6	6.5
Pregnant Solution { KCN, per cent.	0.1275	0.131	0.129	0.128
{ CNBr, per cent.	0.0068	0.0031	0.0021	0.0016
{ CaO, per cent.	0.005	0.035	0.034	0.035
KCN Consumption, lb. per ton	0.470	0.400	0.440	0.460
Head Value, dwt. Au per ton	15.2	15.2	15.2	15.2
Residue Value, dwt. Au per ton	2.4	2.4	2.4	3.4
Extraction, per cent.	84.21	84.21	84.21	77.63

This test also shows that regeneration of cyanide takes place during the first half hour's agitation after addition of lime and that from that time onward a gradual decomposition of the free cyanide takes place which is accompanied by a gradual decomposition also of the residual cyanogen bromide, while the protective alkalinity of the solution remains practically constant after the first half hour's agitation.

The cyanide consumptions shown are based on the percentages of free cyanide in the solution at each sampling, and show a minimum half an hour after addition of lime, indicating that by that time the whole of the free hydrocyanic acid in the solution has been converted to alkaline earth cyanide which is then included in the free cyanide determined in the usual way by titration with silver nitrate solution. Thereafter, apparently, decomposition of cyanide takes place on continued agitation, so that from the point of view of the consumption of cyanide, prolonged agitation after the final addition of lime is a disadvantage. The low cyanide and protective alkali values of the solution immediately after the addition of lime show that time must be allowed for the action of the added lime in neutralising free hydrocyanic acid and for the solution of the lime. Half an hour appears to be sufficient to obtain the full effect of the lime, as the cyanide and protective alkali values of the solution then reach a maximum, the protective alkali from that time onward remaining constant, while the free cyanide gradually decomposes. Therefore, agitation for half an hour after addition of lime is necessary and this period should not be exceeded.

Confirmation of the result of Test 157 being desirable in order to establish definitely the effect of prolonged agitation after the final addition of lime, a further test was carried out on a new sample of Golden Horseshoe ore, assaying 12.4 dwt. gold per ton, under similar conditions to those adopted in Test 157, the period of agitation being still further prolonged after the final addition of lime. Of this sample 98.8 per cent. passed a 200-mesh screen. The conditions and the result of this test are shown in the following table.

EFFECT OF CONTINUED AGITATION AFTER FINAL ADDITION OF LIME.

Golden Horseshoe Ore - 12.4 dwt Au per ton.

TEST 158.

Treatment conditions: Ore charge 1200 gram
 Barren solution, { Volume 1200 c.c.
 { KCN, % 0.151
 CNBr added 1 lb. per ton
 Agitation time { With KCN 3 hours
 { With CNBr 2 hours
 CaO added after five hours, 2 lb. per ton.

Results:

Time, hours	5	5.5	6	6.5	7	7.5	
Pregnant solution {	KCN, per cent.	0.0071	0.122	0.125	0.125	0.122	0.122
	CNBr, per cent.	0.0068	0.0031	0.0010	0.0008	0.0008	0.0006
	CaO, per cent. acid		0.013	0.013	0.014	0.014	0.012
KCN Consumption, lb. per ton	1.6	0.58	0.52	0.52	0.58	0.58	
Residue value, dwt. Au per ton	1.2	1.2	1.2	1.2	2.8	3.2	
Extraction, per cent.	89.8	89.8	89.8	89.8	77.4	74.2	

The sample taken at five hours was removed before adding the lime and the filtrate from the sample showed an acid reaction and a low percentage of cyanide. When, however, the filtrate was made alkaline by adding lime water and the cyanide content was determined immediately, it was found that the cyanide content had increased to 0.115 per cent., showing that free hydrocyanic acid had previously been present, and reducing the actual cyanide consumption to 0.72 lb. per ton.

The results show that the free cyanide content of the solution increases during the first hour after the addition of lime, remains constant for half an hour and then diminishes again. The protective alkalinity, as in Test 157, reaches a practically constant value after half an hour's agitation with the lime. The value of the residue remains constant until one and a half hours after the addition of lime and then increases, indicating that reprecipitation of the gold takes place after that time. The cyanide consumption reaches a minimum one hour after addition of lime and again increases after one and a half hour's agitation with lime, owing probably to decomposition of cyanide.

In order to confirm the effect of the addition of lime at the beginning of the treatment, a further series of tests was carried out on the new sample of Golden Horseshoe ore under similar conditions to those obtaining in Tests 149, 150, 152 and 153. The results, shown in the following table, confirm the conclusions arrived at from the results of the previous series of tests, that although the consumption of cyanide is thereby considerably diminished the extraction of gold is also affected in the same way. These results all point to the fact that during bromocyanidation the protective alkalinity of the solution must be carefully controlled and that the best results are obtained when the protective alkalinity of the solution is maintained at a minimum or when the solution is slightly acid.

EFFECT OF INITIAL ADDITION OF LIME.

Golden Horseshoe Ore.

Test No.	159	160	161	162
Ore, weight, gram	200	200	200	200
Barren solution (Volume, c.c. (KCN, per cent.)	200	200	200	200
CNBr added, lb. per ton	0.151	0.151	0.151	0.151
Agitation time, hours (With KCN (With CNBr	1	1	1	1
CaO additions, lb. per ton (Initial (Final	2	2	2	2
	2	2	2	2
Pregnant solution (KCN, per cent. (CNBr, per cent. (CaO, per cent.	0.137	0.137	0.122	0.126
	0.0015	0.0010	0.0010	0.0010
	0.029	0.026	0.035	0.021
KCN Consumption, lb. per ton	0.28	0.28	0.58	0.50
Head value, dwt. Au per ton	12.4	12.4	12.4	12.4
Residue value, dwt. Au per ton	2.8	3.6	2.9	2.8
Extraction, per cent.	77.42	70.97	76.61	77.42

These tests also show that the consumption of cyanide is increased by the longer period of agitation and that there is no appreciable increase in the percentage extraction during the longer period of treatment. This confirms the results of previous tests on this ore in which treatment was carried out for three and five hour periods.

For the purpose of determining the effect of the introduction of amalgamation before the bromocyanidation, a sample, assaying 12.8 dwt. gold per ton, was amalgamated during grinding, to furnish a sample for cyanidation. The ore after amalgamation assayed 7.7 dwt. gold per ton, showing an extraction of 5.1 dwt. gold per ton, or 39.48 per cent. of the gold. Evidently, a comparatively large proportion of the gold in this sample of ore is present in the free state and is readily recovered by amalgamation during fine grinding. Tests were carried out on this sample under conditions similar to those of Tests 142, 143, and 144. Since it had previously been found that it was inadvisable to extend the total time of treatment beyond three hours, these tests were carried out for that period. Two bromocyanidation tests and one test using plain cyanide were carried out side by side for the purpose of obtaining comparative results by the two methods. The results of these tests are shown in the following table.

EFFECT OF AMALGAMATION BEFORE CYANIDATION.

Golden Horseshoe Ore.

Test No.	163	164	165
Ore, weight, gram	200	200	200
Barren solution, (Volume, c.c. (KCN, per cent.)	200	200	200
CNBr added, lb. per ton	0.151	0.151	0.151
Agitation time, hours (With KCN (With CNBr	0	1	1
CaO additions, lb. per ton (Initial (Final	3	2	2
	-	1	1
Pregnant solution, (KCN, per cent. (CNBr, per cent. (CaO, per cent.	0	0	0
	2	2	2
	0.1215	0.101	0.1025
KCN Consumption, lb. per ton	-	0.0042	0.0032
Head value after amalgm., dwt. Au per ton	0.015	0.003	0.010
Residue value, dwt. Au per ton	0.59	1.00	0.97
Extraction, per cent.	7.7	7.7	7.7
	2.15	1.5	1.5
	72.08	80.52	80.52
<u>Total Extractions.</u>			
By Amalgamation, per cent.	39.84	39.84	39.84
By Cyanidation, per cent.	43.36	48.44	48.44
Total, per cent.	83.20	88.28	88.28

In comparison with that of most other similar tests, the consumption of cyanide in these tests is exceptionally high, and, consequently, duplicates of Tests 164 and 165 have been carried out, and, in addition, similar tests have been carried out on the amalgamated pebble mill product for the longer agitation period of five hours with plain cyanide and of three hours with plain cyanide and a subsequent two hours after addition of one pound of cyanogen bromide per ton. In all these tests on amalgamated ore, lime has been added only at the completion of the agitation period in order to keep the solution as low in protective alkalinity during the bromocyanidation as possible, since this condition tends to yield the highest extraction. Tests 166 and 167, which are duplicates of Tests 164 and 165, confirm the results of those tests as regards the high consumption of cyanide, which appears to be higher in the treatment of amalgamated ore than of raw ore, and also higher, as might be expected, when no lime is added at the commencement of agitation, although agitation with an acid solution or one possessing only slight protective alkalinity appears to result in higher extraction than when the solution is maintained alkaline by addition of lime at the commencement of the treatment. The lower extraction in an alkaline solution is in this case, no doubt, due to the more rapid decomposition of cyanogen bromide which is more stable in acid or neutral than in alkaline solution. The longer period of agitation, both with and without cyanogen bromide, appreciably increases the consumption of cyanide.

The results of this series of tests are shown in the following table.

EFFECT OF AMALGAMATION BEFORE CYANIDATION.

Golden Horseshoe Ore.

Test No.	166	167	168	169	170
Ore, weight, gram	200	200	200	200	200
Barren solution (Volume, c.c.)	200	200	200	200	200
(KCN, per cent.)	0.149	0.149	0.149	0.149	0.149
CNBr added, lb. per ton	1	1	-	1	1
Agitation time, hours (with KCN)	2	2	5	3	3
(with CNBr)	1	1	-	2	2
CaO added, lb. per ton, final	2	2	2	2	2
Pregnant solution (KCN, per cent.)	0.099	0.098	0.1115	0.0905	0.088
(CNBr, per cent.)	0.0021	0.0031	-	0.0016	0.0016
(CaO, per cent.)	0.006	0.008	0.011	0.009	0.008
KCN Consumption, lb. per ton	1.00	1.02	0.75	1.17	1.22
Head value, dwt. Au per ton	7.7	7.7	7.7	7.7	7.7
Residue value, dwt. Au per ton	2.5	2.4	4.0	2.2	2.3
Extraction, per cent.	67.53	68.83	48.65	71.43	70.13
<u>Total Extractions, per cent.</u>					
By amalgamation	39.84	39.84	39.84	39.84	39.84
By cyanidation	40.62	41.40	28.90	42.97	42.18
Total	80.46	81.24	68.74	82.79	82.02

As in previous tests under similar conditions, the consumption of cyanide is high, and the extraction, by cyanidation is lower than in the previous tests, there being practically no difference between the extractions obtained in the different periods of treatment. These tests on amalgamated ore lead to the conclusion that no advantage is gained by amalgamation before cyanidation in the case of this ore, and that that treatment is only advisable when the ore contains gold which is too coarse to be dissolved in cyanide solution within a reasonable time.

For the purpose of ascertaining the effect of adding cyanogen bromide in two equal portions at equal intervals of time, Tests 171 - 174 have been carried out on Golden Horseshoe pebble mill product, in which two half-pound additions of cyanogen bromide were made at the

commencement of and midway through the respective periods of agitation with that reagent. Lime was added only on completion of the agitation, and consequently, the consumption of cyanide was in each case comparatively high, although similar to that in Tests 143, 144, 146, and 147, which were carried out under similar conditions, except that the whole of the cyanogen bromide was added at once. The results of these tests are shown in the following table.

EFFECT OF ADDITION OF CYANOGEN BROMIDE AT EQUAL INTERVALS.

Golden Horseshoe Ore - Assay value, 12.4 dwt. Au per ton.

Treatment conditions : Pulp ratio, 1 : 1
 Barren solution, KCN per cent. 0.149
 CNBr added, 1 lb. per ton
 CaO added at end of test, 2 lb. per ton

Test No.	171	172	173	174
Agitation time, hours (With KCN)	2	2	3	3
(With CNBr)	1	2	2	2
Pregnant solution, (KCN, per cent.)	0.105	0.105	0.096	0.097
(CNBr, per cent.)	0.0053	0.0053	0.0016	0.0021
(CaO, per cent.)	0.005	0.006	0.005	0.008
KCN Consumption, lb. per ton	0.88	0.88	1.06	1.04
Residue value , dwt. Au per ton	2.7	3.2	1.7	2.0
Extraction, per cent.	78.22	74.19	86.29	83.87

On account of the high consumption of cyanide and the comparatively low extraction obtained in the treatment of Golden Horseshoe ore after amalgamation, Tests 163 - 170, a second series of tests was carried out on a new sample of the same ore, amalgamated during fine grinding in the pebble mills, in which two different periods of treatment were adopted and treatment took place with and without the addition of lime at the commencement of the agitation. When no lime was added at the commencement of the treatment, the consumption of cyanide was appreciably higher than when lime was initially added, while in either case the consumption of cyanide was high when compared with that usually found in the treatment of the same ore without previous amalgamation.

This sample of ore assayed before amalgamation 18.2 dwt. gold per ton, and after amalgamation 16.0 dwt. gold per ton, showing an extraction by amalgamation of 12.14 per cent. of the gold. The extraction by cyanidation and bromocyanidation was in all cases higher when no initial lime was added than when such addition was made, and there was no appreciable difference between the results obtained by increasing the agitation period with plain cyanide from two to three hours and with cyanogen bromide from one to two hours. The results show conclusively that during treatment with cyanogen bromide the protective alkalinity of the solution should be kept as low as possible on account of the destructive action of the alkali on cyanogen bromide. The results of this series of tests are shown in the following table.

EFFECT OF AMALGAMATION BEFORE CYANIDATION.

Golden Horseshoe Ore - Before amalgamation, 18.2 dwt. Au per ton
 After amalgamation, 16.0 dwt. Au per ton
 Extraction by amalgam. 2.2 dwt. Au per ton
 = 12.14 per cent.

Treatment conditions: Pulp ratio, 1 : 1
 Barren solution, KCN, per cent., 0.151
 CNBr added, 1 lb. per ton

Test No.	175	176	177	178	179	180	181	182
Agitation time, hrs (KCN)	2	2	2	3	3	3	3	3
(CNBr)	1	1	1	1	2	2	2	2
CaO addition (Initial)	-	-	2	2	-	4	2	2
(Final)	2	2	2	2	2	2	2	2
Pregnant Solution (KCN, %)	0.106	0.104	0.119	0.122	0.106	0.104	0.116	0.115

EFFECT OF AMALGAMATION BEFORE CYANIDATION (continued).

Test No.	175	176	177	178	179	180	181	182
Pregnant (CNBr, %)	0.0032	0.0052	0.0076	0.0052	0.0040	0.0036	0.0024	0.0028
(CaO, %)	0.006	0.006	0.052	0.055	0.006	0.007	0.046	0.038
KCN Consumption, lb. per ton	0.90	0.94	0.64	0.58	0.90	0.94	0.70	0.72
Residue, dwt/ton	1.9	1.8	3.6	2.8	1.8	1.8	3.2	3.3
Extraction, %	88.12	88.75	77.50	82.50	88.75	88.75	80.00	79.37
<u>Total Extractions.</u>								
By amalgamation	12.14	12.14	12.14	12.14	12.14	12.14	12.14	12.14
By cyanidation	77.47	78.02	68.13	72.53	78.02	78.02	70.33	69.78
Total	89.61	90.16	80.27	84.67	90.16	90.16	82.47	81.92

The results of these tests draw attention to the fact that in the treatment of a comparatively high grade ore amalgamation tends to give an increased extraction and that no advantage is gained by increasing the total cyanidation time from three to five hours. The effect of the initial addition of lime on the extraction of gold is very marked, confirming the conclusion, previously arrived at, that during bromocyanidation the protective alkalinity of the solution must be maintained as low as possible, although this treatment condition causes an increased consumption of cyanide during treatment. Therefore, two conflicting conditions have to be considered, namely, whether to sacrifice extraction for cyanide consumption, or vice versa. As, however, the consumption of cyanide seldom exceeds one pound per ton when no lime is added initially and the reduction in consumption due to such addition is comparatively small and more than compensated for by the increased extraction resulting from the treatment with a minimum of protective alkalinity, it is evident that it is more economical to secure the increased extraction of gold at the expense even of half a pound of cyanide per ton of ore, rather than to sacrifice the extraction for the sake of a lower cyanide consumption. Although a ninety per cent. extraction may reasonably be expected under the conditions set out in the table when no initial addition of lime is made, the final residue from the relatively high grade ore is too high. At the same time the short time of treatment has to be taken into account with its comparatively small cost and increased capacity of plant, which are considerations that will probably more than compensate for the loss in the residues.

Since the results of Tests 171 - 174, in which cyanogen bromide was added to the pulp at intervals were inconclusive, further tests were carried out on the same product under similar conditions, but at the same time comparative tests were carried out to determine also the effect of the initial addition of lime on the results by this method of adding the cyanogen bromide. These tests confirm the conclusions previously arrived at regarding the inadvisability of adding lime at the commencement of the treatment, as in all tests where this was done, the extraction of gold was less than when no lime was initially added, although this addition of lime resulted in a considerable decrease in the consumption of cyanide. This sample of ore was not previously amalgamated and it appears that by adding the cyanogen bromide at intervals and by prolonging the time of treatment to five hours, ninety per cent. extraction can be obtained without amalgamation and with the production also of a residue of reasonably low grade. In these tests the cyanogen bromide was added in two equal portions of 0.5 lb. per ton of ore; in Tests 183 - 186 the additions were made at intervals of half an hour and in Tests 187 - 190 at intervals of one hour. The pregnant solutions from all these tests contained more cyanogen bromide than was expected, indicating that in all probability the time of treatment after the second addition was too short. The results of these tests are shown in the following table.

EFFECT OF ADDITION OF CYANOGEN BROMIDE AT INTERVALS.Golden Horseshoe Ore, Assay value - 12.4 dwt. Au per ton.

Treatment conditions : Pulp ratio, 1 : 1.
 Barren solution, 0.151 per cent. KCN.
 Cyanogen bromide added, 1 lb. per ton.

Test No.	183	184	185	186	187	188	189	190
Agitation (with KCN	2	2	2	2	3	3	3	3
time, hrs. (with CNBr	1	1	1	1	2	2	2	2
CaO added (Initial	-	-	2	2	-	-	2	2
lb. per ton (Final	2	2	2	2	2	2	2	2
Pregnant (KCN, %	0.112	0.117	0.135	0.137	0.111	0.109	0.141	0.142
solution (CNBr, %	0.010	0.0088	0.004	0.004	0.0048	0.0048	0.006	0.0056
(CaO, %	0.001	0.002	0.026	0.026	0.001	0.002	0.019	0.015
KCN Consumption,								
lb. per ton	0.78	0.68	0.32	0.28	0.80	0.84	0.20	0.18
Residue value,								
dwt. Au per ton	2.0	1.8	3.1	4.5	1.2	1.2	1.9	2.7
Extraction, per								
cent.	83.87	85.48	75.00	63.71	90.32	90.32	85.48	78.22

For the purpose of demonstrating the accelerating action of cyanogen bromide on the solution of the gold during short periods of agitation, and also to furnish a comparison between the results obtainable by treatment with plain cyanide solution for periods of time varying from two hours up to five hours, the maximum time adopted in the bromocyanide tests, a series of tests was carried out on Golden Horseshoe ore prepared in the usual way, in which cyanide alone was used for treatment with and without the addition of lime at the commencement of the treatment. Except in the case of the two-hour agitation period, the extraction was in each case higher when lime was added at the commencement of the agitation period, due, no doubt, to the protective action of the alkali preventing decomposition of the cyanide during treatment and thus increasing the solvent strength of the solution. In each test where lime was added, the consumption of cyanide was comparatively low, while in the other tests the consumption was very considerably increased. The pregnant solutions in the former tests showed protective alkalinity, while in the latter tests the solutions were acid to phenolphthalein and the solution contained free hydrocyanic acid; in the latter tests the free cyanide content of the pregnant solutions was determined before and after neutralisation of the free acid with lime, so that two values for the cyanide content are shown in the results of these tests. The lower cyanide value represents the actual alkaline cyanide content after treatment, while the higher value, obtained after neutralisation of the free hydrocyanic acid by means of lime water, represents the sum of the free cyanide and hydrocyanic acid expressed in terms of potassium cyanide. Consequently, also, two values are given for the cyanide consumption, based on the two values of the cyanide strength of the pregnant solution. The cyanide consumption calculated on the KCN + HCN content of the solution is the practical value since, in practice, it would be necessary to neutralise the acidity with lime in order to secure efficient precipitation of the gold. In no case, however, does the cyanide content of the solution after neutralisation approach that of the solution resulting from the similar treatment with initial addition of lime, showing that in the absence of protective alkalinity, decomposition of the cyanide takes place with the production of compounds from which alkaline cyanide can not be regenerated by the subsequent addition of lime. That is to say, the initial addition of lime exerts a protective influence on the cyanide during treatment and therefore the concentration of the solution is better maintained throughout the treatment period, with a consequent increase in the efficiency of the solution as a solvent of the gold. In those tests in which the pregnant solution was acid, the acidity has been expressed as negative alkalinity and the amount of acidity is shown in terms of the percentage of lime necessary to neutralise this acidity.

This series of tests shows that even in the comparatively short agitation period of five hours, the extraction of gold by plain cyanide solution is quite high, but when the results of these tests are compared with those of similar tests in which cyanogen bromide was added and in which the total time of agitation with cyanide and cyanogen bromide was the same as the time of agitation with plain cyanide in this series, the accelerating action of the cyanogen bromide on the dissolving action of the potassium cyanide is clearly shown.

The results of this series of tests are shown in the following table.

EFFECT OF TREATMENT WITH CYANIDE ALONE.

Golden Horseshoe Ore, Assay value - 9.75 dwt. Au per ton.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.151 per cent. KCN.

Test No.	191	192	193	194	195	196	197	198
Agitation time, hrs.	2	2	3	3	4	4	5	5
Initial addition of CaO, lb. per ton	-	2	-	2	-	2	-	2
Pregnant solution (KCN, %)	0.107	0.142	0.1025	0.139	0.107	0.131	0.104	0.136
(KCN+HCN, %)	0.126	-	0.121	-	0.121	-	0.121	-
(CaO, %)	-0.0099	0.009	-0.0085	0.015	-0.012	0.012	-0.043	0.015
Consumption of KCN, lb. per ton (Apparent)	0.88	-	0.97	-	0.88	-	0.94	-
(Actual)	0.50	0.18	0.60	0.24	0.60	0.40	0.60	0.30
Residue value, dwt.	5.8	6.8	5.8	5.2	7.6	5.7	4.8	4.2
Au per ton	5.8	6.8	5.8	5.2	7.6	5.7	4.8	4.2
Extraction, per cent.	40.51	30.25	40.51	46.66	22.05	41.53	50.77	56.92

To obtain information regarding the progress of extraction of the gold during varying times of treatment with both cyanide and cyanogen bromide and at the same time to determine the effect of initial addition of lime, a series of tests was carried out in which agitation with cyanide alone was continued for two, three, and four hours, while, after addition of 1 lb. cyanogen bromide per ton of ore, agitation was continued for one, two, and two hours, respectively. These tests were carried out in pairs, one of each pair having no initial addition of lime, the other having two pounds of lime added per ton of ore at the commencement of the agitation. No lime was added at the completion of the treatment so as to make it possible to determine whether at the end of the period the solution was alkaline or acid. Where no lime was added at the commencement of the agitation, the solution showed acidity at each sampling time, whereas, when lime was added, the solution showed alkalinity in spite of the acidity of the stock cyanogen bromide solution. Samples of the charges were taken in each case at the end of the period of agitation with plain cyanide solution and also one and two hours after the addition of cyanogen bromide.

The results of this series are shown in the following table.

PROGRESS OF EXTRACTION WITH CYANIDE AND CYANOGEN BROMIDE.Golden Horseshoe Ore, Assay value - 9.75 dwt. Au per ton.

Treatment conditions : Pulp ratio, 1 : 1.
 Barren solution, 0.151 per cent. KCN.
 CNBr added, 1 lb. per ton of ore.

Test No.	199	200	201	202	203	204
Agitation time, hrs. (With KCN)	2	2	3	3	4	4
(With CNBr)	1	1	2	2	2	2
Initial CaO addition, lb. per ton	-	2	-	2	-	2
"A" Sample, after agitation for	2 hr.	2 hr.	2 hr.	2 hr.	2 hr.	2 hr.
Pregnant solution (KCN, %)	0.115	0.142	0.106	0.136	0.093	0.123
(KCN+HCN, %)	0.139	-	0.120	-	0.115	-
(CaO, %)	-0.011	0.016	-0.009	0.015	-0.012	0.030
KCN Consumption, lb. per ton						
(Apparent)	0.72	-	0.90	-	1.16	-
(Actual)	0.24	0.18	0.62	0.30	0.72	0.56
Residue value, dwt. Au per ton	4.4	4.6	3.9	3.6	3.4	3.8
Extraction, per cent.	54.87	52.82	60.00	53.07	65.12	61.02
"B" Sample, after agitation for	3 hr.	3 hr.	4 hr.	4 hr.	5 hr.	5 hr.
Pregnant solution (KCN, %)	0.089	0.135	0.075	0.135	0.075	0.110
(KCN+HCN, %)	0.117	-	0.120	-	0.093	-
(CaO, %)	-0.014	0.010	-0.032	0.005	-0.025	0.005
(CNBr, %)	0.009	0.005	0.011	0.009	0.006	0.007
KCN Consumption, (Apparent)	1.24	-	1.52	-	1.52	-
lb. per ton (Actual)	0.68	0.32	0.62	0.32	1.16	0.82
Residue value, dwt. Au per ton	1.6	1.8	1.0	2.0	0.8	1.8
Extraction, per cent.	83.59	81.53	89.73	79.48	91.79	81.53
"C" Sample, after agitation for			5 hr.	5 hr.	6 hr.	6 hr.
Pregnant solution (KCN, %)			0.072	0.130	0.072	0.112
(KCN+HCN, %)			0.110	-	0.093	-
(CaO, %)			-0.025	0.005	-0.020	0.0025
(CNBr, %)			0.010	0.009	0.006	0.005
KCN Consumption, (Apparent)			1.58	-	1.58	-
lb. per ton (Actual)			0.82	0.42	1.16	0.78
Residue value, dwt. Au per ton			1.0	2.0	0.7	2.0
Extraction, per cent.			89.73	79.48	92.82	79.48

In stating the results of these tests the same method of determination and expression of, the free cyanide and hydrocyanic acid content and alkalinity and acidity of the solution has been adopted as in Tests 191 - 198, while the cyanide consumptions shown are progressive totals.

These tests show again the advantage, from the point of view of gold extraction, obtained by carrying out the treatment in a pulp which, at the completion of the treatment, shows slight acidity instead of protective alkalinity and that regeneration of free cyanide by neutralisation of the hydrocyanic acid by means of lime, as is necessary in practice before precipitation, reduces the cyanide consumption to a reasonable figure.

With this ore, increasing the time of treatment from three hours with KCN and one hour with cyanogen bromide to four hours with KCN and one hour with CNBr gives such a slight increase in extraction that treatment for the longer period is not necessary, although in practice the exigencies of plant control may necessitate treatment being continued for longer periods until the agitation charge can be sent to filtration, in which case the increased extraction will be obtained at the expense of

a somewhat increased cyanide consumption.

In order to determine the effect of a long agitation with cyanide alone and the increased extraction due to the addition of cyanogen bromide subsequent to the long agitation with cyanide, two tests have been carried out on Golden Horseshoe ore in which agitation with 0.151 per cent. KCN solution, with and without initial addition of lime, was continued for forty eight hours, after which one pound of cyanogen bromide per ton of ore was added to each charge and agitation continued in each case for four hours. Sampling of the charge was performed after 48, 50 and 52 hours' agitation, and no final addition of lime was made to the charges so that the acidity of the resulting solutions might be determined.

The treatment conditions and the results of these two tests are shown in the following table and bear out the conclusion, previously arrived at, that initial addition of lime has a harmful effect on the gold extraction when cyanogen bromide is used, although it results in an appreciable reduction in the cyanide consumption.

EFFECT OF LONG AGITATION WITH KCN BEFORE ADDITION OF CNBr.

Golden Horseshoe Ore, Assay value - 9.75 dwt. Au per ton.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.151 per cent. KCN.
CNBr added, 1 lb. per ton of ore.
Agitation time, with KCN, 48 hours.
" " with CNBr, 4 hours.
Charges sampled after 48, 50, and 52 hours.

Test No.	205	206
Initial addition of CaO, lb. per ton	-	2
<u>48-hour Sample, KCN treatment alone</u>		
Pregnant solution, { KCN, per cent.	0.063	0.109
{ KCN+HCN, per cent.	0.075	-
{ CaO, per cent.	-0.002	0.004
KCN Consumption, lb. per ton { Apparent	1.76	-
{ Actual	1.52	0.84
Residue value, dwt. Au per ton	3.0	2.2
Extraction, per cent.	69.23	77.43
<u>50-hour Sample, 48 hours KCN, 2 hours CNBr</u>		
Pregnant solution, { KCN, per cent.	0.048	0.107
{ KCN+HCN, per cent.	0.068	-
{ CaO, per cent.	-0.016	0.001
{ CNBr, per cent.	0.0296	0.0104
KCN Consumption, lb. per ton { Apparent	0.30	-
{ Actual	0.14	0.04
Residue value, dwt. Au per ton	1.0	1.0
Extraction, per cent.	89.74	89.74
<u>52-hour Sample, 48 hours KCN, 4 hours CNBr</u>		
Pregnant solution, { KCN, per cent.	0.028	0.100
{ KCN+HCN, per cent.	0.053	0.112
{ CaO, per cent.	-0.028	-0.015
{ CNBr, per cent.	0.016	0.0016
KCN Consumption, lb. per ton { Apparent	0.40	0.14
{ Actual	0.30	-0.10 (gain)
Residue value, dwt. Au per ton	0.6	1.0
Extraction, per cent.	93.84	89.74
Total KCN Consumption, lb. per ton { Apparent	2.46	-
{ Actual	1.96	0.78

These tests furnish the following important results :-

1. Prolonged agitation with plain cyanide solution yields a comparatively

- high percentage extraction of gold in both cases.
2. The consumption of cyanide after forty eight hours' agitation with plain cyanide solution is very high in both tests.
 3. The consumption of cyanide after forty eight hours' agitation with plain cyanide solution is higher in the absence of protective alkalinity than when the resulting solution shows a trace of alkalinity.
 4. When no lime is added at the commencement of the treatment, the solution shows acidity after forty eight hours' agitation with plain cyanide solution.
 5. During the first two hours' agitation after addition of cyanogen bromide the decomposition of that reagent is much greater in the alkaline pulp than in the slightly acid pulp, this being due to the decomposing action of alkalis on cyanogen bromide.
 6. The first two hours' agitation after the addition of cyanogen bromide results in an increased extraction of over twenty per cent. of the gold.
 7. During the second period of two hours after the addition of cyanogen bromide the decomposition of that reagent is much more rapid in the alkaline pulp than in the acid pulp.
 8. In consequence of the slower decomposition of cyanogen bromide in an acid pulp, its solvent action is greater than in the alkaline pulp and therefore the extraction is higher in the acid than in the alkaline pulp.
 9. In the alkaline pulp no increase in extraction is obtained during the second two hour period of agitation after addition of cyanogen bromide.
 10. In the acid pulp the increase in extraction during the latter half of the period of agitation with cyanogen bromide is very much less than during the first half of the period.
 11. The actual consumption of cyanide during the period of agitation with cyanogen bromide is comparatively low, both in alkaline and in acid pulp, the former showing an extremely low consumption of cyanide.
 12. The greater portion of the cyanide consumption takes place during the period of agitation with plain cyanide solution.

EFFECT OF STRONG CYANIDE SOLUTION.

In a previous series of Tests, Nos. 50 - 55, it was found that increasing the concentration of the cyanide solution from 0.15 per cent to 0.2 and 0.25 per cent KCN resulted in a diminished extraction of the gold. Further information being necessary on this point, in order to determine the maximum effective concentration of cyanide solution for the treatment of ores of average grade and to ascertain whether the information previously obtained was reliable, series of tests have been carried out on Golden Horseshoe ore in which a 0.2 per cent. cyanide solution was employed. Simultaneously with these tests and included in the series, tests have been carried out in which all other treatment conditions except addition of cyanogen bromide have been the same as in the bromocyanide tests. These have been carried out to determine the extraction obtained by plain cyanide solution under similar conditions to those obtaining in the bromocyanide tests, and to show the accelerating action of cyanogen bromide on the solution of the gold. In the bromocyanide tests one pound of cyanogen bromide per ton of ore has been added after two and three hours' agitation with the cyanide solution alone and the agitation continued subsequently for a further period of one and two hours, respectively. In this series, duplicate tests have been run, with and without initial addition of lime, in order to determine the effect on extraction and cyanide consumption, while no lime has been added at the end of the agitation period so that the actual condition of the cyanide solution after treatment might be determined. As in previous tests with 0.15 per cent. cyanide solution, the consumption of cyanide is materially affected by the addition or non-addition of lime at the beginning of the treatment, a saving of 0.5 lb. or more of KCN per ton of ore being brought about by adding 2 lb. CaO per ton of ore at the commencement of the treatment, although in the case of the bromocyanide tests the extraction of gold is greatly diminished by the initial addition of lime, due, no doubt, to the decomposition of the cyanogen bromide by the caustic alkali greatly diminishing the effective amount of cyanogen

EFFECT OF STRONG CYANIDE SOLUTION.

Golden Horseshoe Ore, Assay value, 11.1 dwt. Au per ton.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.198 per cent. KCN.

Test No.	207	208	209	210	211	212	213	214	215	216	217	218
CNBr added, lb. per ton	-	-	1	1	1	1	-	-	1	1	1	1
Agitation time (With KCN)	3	3	2	2	2	2	5	5	3	3	3	3
hours (With CNBr)	-	-	1	1	1	1	-	-	2	2	2	2
Initial CaO addition, lb. per ton	-	2	-	-	2	2	-	2	-	-	2	2
Pregnant solution (KCN+HCN, %)	0.168	0.187	0.129	0.127	0.177	0.170	0.161	0.185	0.125	0.127	0.179	0.179
(CNBr, %)	-	-	0.143	0.141	-	-	-	-	0.1355	0.140	-	-
(CaO, %)	0.002	0.025	0.0096	0.0112	0.0036	0.0028	-	-	0.0094	0.0082	0.0074	0.009
Consumption of KCN, lb. per ton	-	-	-0.0055	-0.0045	0.020	0.017	0.002	0.022	-0.0055	-0.0065	0.011	0.013
Residue value, dwt. Au per ton	6.8	7.4	1.8	1.6	6.4	6.8	6.8	7.2	1.6	1.2	5.6	4.4
Extraction, per cent.	20.72	33.33	83.78	85.58	42.34	38.73	35.13	35.13	89.19	49.55	60.36	60.36
							38.73	35.13	85.58	89.19	49.55	49.55

The diminished cyanide consumption resulting from the initial addition of lime to the treatment charge is very marked, but at the same time, the very much greater loss of gold in the residues when this course is adopted does not counterbalance the saving in cyanide, while, in practice, the lime would be added after the treatment in order to bring the alkalinity of the solution up to the correct amount for efficient precipitation. Therefore, it is preferable to add no lime during bromocyanidation and to sacrifice cyanide in favour of an increased gold extraction. These tests again show the benefit derived from having the solution slightly acid during bromocyanide treatment and the harmful effect of alkaline solutions. In the latter case, the extraction by bromocyanidation is but little better than that obtained by treatment with cyanide alone.

EFFECT OF WEAK CYANIDE SOLUTION.

In a previous series of tests, Nos. 59 - 97, it was found that under otherwise similar conditions a 0.1 per cent. cyanide solution gave lower extractions than a 0.15 per cent. solution. In order to obtain further information regarding the effect of using a weak cyanide solution, a series of tests has been carried out on Golden Horseshoe ore under similar conditions to those adopted in the previous series of tests on the effect of using a stronger solution than 0.15 per cent. KCN. The treatment conditions and the results of this series are shown in the following table.

EFFECT OF WEAK CYANIDE SOLUTION.

Golden Horseshoe Ore - Assay value, 11.1 dwt. Au per ton.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.099 per cent. KCN.

Test No.	219	220	221	222	223	224	225	226	227	228	229	230
CNBr added, lb. per ton	-	-	1	1	1	1	-	-	1	1	1	1
Agitation { With KCN	3	3	2	2	2	2	5	5	3	3	3	3
time, hrs. { With CNBr	-	-	1	1	1	1	-	4	2	2	2	2
Initial addition of CaO lb. per ton	-	2	-	-	2	2	-	2	-	-	2	2
Pregnant solution { KCN, per cent.	0.073	0.090	0.049	0.048	0.090	0.091	0.065	0.089	0.040	0.041	0.087	0.084
{ KCN+HCN, %	0.081	-	0.066	0.060	-	-	0.074	-	0.059	0.060	-	-
{ CNBr, %	-	-	0.010	0.0094	0.0088	0.008	-	-	0.0116	0.0116	0.0056	0.0072
{ CaO, %	-0.0025	0.011	-0.009	-0.011	0.011	0.010	-0.0035	0.016	-0.0065	-0.0075	0.006	0.005
Consumption of { Apparent KCN, lb. per	0.52	-	1.00	1.02	-	-	0.68	-	1.18	1.16	-	-
{ Actual ton	0.36	0.18	0.66	0.78	0.18	0.16	0.50	0.20	0.80	0.78	0.24	0.30
Residue value, dwt. Au per ton	9.5	7.2	2.6	2.2	6.6	5.6	10.0	7.6	1.4	1.5	4.9	4.8
Extraction, per cent.	14.41	35.13	76.57	80.18	40.54	49.55	9.91	31.53	87.38	86.48	55.85	56.75

The cyanide consumption and the alkalinity of the pregnant solution show a similar relationship but are less than those obtained in the previous series in which 0.2 per cent cyanide solution was used, while the extraction of gold in the bromocyanide tests in which no lime was added differs very little from that obtained with the stronger solution.

For the purpose of completing the comparison between the results of the treatment of this ore with cyanide solutions of the three different concentrations, viz., 0.099 per cent., 0.148 per cent., and 0.198 per cent. KCN, a further series of tests was carried out in which a 0.148 per cent. KCN solution was used, both with and without cyanogen bromide. The treatment conditions and the results of these tests are shown in the following table.

EFFECT OF TREATMENT WITH 0.148 PER CENT. CYANIDE SOLUTION.

Golden Horseshoe Ore - Assay value, 11.1 dwt. Au per ton.

Treatment conditions :- Pulp ratio, 1 : 1.

Cyanide solution, 0.148 per cent. KCN.

Test No.	231	232	233	241	234	242	235	236	237	238
CNBr added, lb. per ton	1	1	1	1	1	1	-	-	-	-
Agitation with KCN	2	2	2	2	2	2	3	3	5	5
Time, hrs. (With CNBr)	1	1	2	2	2	2	-	-	-	-
Initial CaO added, lb. per ton	-	2	-	-	2	2	-	2	-	2
Pregnant solution (KCN, %)	0.099	0.143	0.087	0.089	0.137	0.138	0.118	0.140	0.098	0.124
(KCN+HCN, %)	0.116	-	0.108	0.108	-	-	0.126	-	0.102	-
(CNBr, %)	0.0062	0.002	0.0066	0.008	0.0044	0.0068	-	-	-	-
(CaO, %)	-0.075	0.023	-0.075	-0.008	0.019	0.017	-0.006	0.020	-0.013	0.022
Consumption of KCN, lb. per ton (Appt.)	0.98	-	1.22	1.18	-	-	0.60	-	1.00	-
(Actual)	0.64	0.10	0.80	0.80	0.22	0.20	0.44	0.16	0.92	0.48
Residue, dwt. Au per ton	2.2	5.6	1.2	0.7	4.7	5.55	6.5	7.2	7.6	6.8
Extraction, per cent.	80.18	49.55	89.19	93.69	57.66	50.00	42.34	35.13	31.53	38.74

For the purpose of readily making a comparison between the results of the whole of this series of tests on the same ore with solutions of the three different cyanide concentrations and under the other variations of treatment conditions, these results have been summarised in the following table.

SUMMARY OF EFFECT OF CYANIDE SOLUTIONS OF VARYING CONCENTRATIONS.

	Cyanide alone						Cyanide and Cyanogen Bromide											
	No initial lime			Initial lime			No initial lime						Initial lime					
	KCN, per cent.			KCN, per cent.			KCN, per cent.						KCN, per cent.					
	0.099	0.148	0.198	0.099	0.148	0.198	0.099	0.148	0.198	0.099	0.148	0.198	0.099	0.148	0.198	0.099	0.148	0.198
	<u>Three hours' treatment.</u>																	
Test No.	219	235	207	220	236	208	221	222	231	239	209	210	223	224	232	240	211	212
Residue, dwt. Au per ton	9.5	6.5	8.8	7.2	7.2	7.4	2.6	2.2	2.2	1.3	1.8	1.6	6.6	5.6	5.6	4.7	6.4	6.8
Extraction per cent.	14.41	42.34	20.72	35.13	35.13	33.33	76.57	80.18	80.18	88.28	83.78	85.58	40.54	49.55	49.55	57.65	42.34	38.73
Consumption of KCN, lb. per ton	0.36	0.44	0.70	0.18	0.16	0.22	0.66	0.78	0.64	0.68	1.10	1.14	0.18	0.16	0.10	0.28	0.42	0.56
	<u>Five hours' treatment.</u>																	
Test No.	225	237	213	226	238	214	227	228	233	241	215	216	229	230	234	242	217	218
Residue, dwt. Au per ton	10.0	7.6	6.8	7.6	6.8	7.2	1.4	1.5	1.2	0.7	1.6	1.2	4.9	4.8	4.7	5.55	5.6	4.4
Extraction per cent.	9.91	31.53	38.73	31.53	38.73	35.13	87.38	86.48	89.19	93.69	85.58	89.19	55.85	56.75	57.66	50.00	49.55	60.36
Consumption of KCN, lb. per ton	0.50	0.92	0.74	0.20	0.48	0.26	0.80	0.78	0.80	0.80	1.25	1.16	0.24	0.30	0.22	0.20	0.38	0.38

(65)

The results of this complete series of tests on the same sample of ore show that

1. Treatment with cyanide alone gives a low extraction.
2. For treatment with cyanide alone, a 0.148 per cent. cyanide solution is as effective as a weaker or a stronger solution, although with an increase in concentration there is usually also an increase in the consumption of cyanide.
3. Except for the lessened consumption of cyanide resulting therefrom, practically no advantage is gained by the addition of two pounds of lime per ton of ore when treating with cyanide alone.
4. When treating with cyanide and cyanogen bromide, the longer period of treatment gives slightly higher extractions than are obtained by the shorter period of treatment, irrespective of the concentration of the cyanide solution.
5. The addition of sufficient lime at the commencement of the treatment with cyanide and cyanogen bromide, so as to ensure that the pregnant solution shall possess protective alkalinity after treatment is complete, always lowers the extraction to such an extent as to render the process impracticable. At the same time, this addition of lime materially lowers the consumption of cyanide, but not to such an extent as to compensate for the greater loss of gold in the residues. Hence, for successful treatment with cyanide and cyanogen bromide, the treatment solution should show no protective alkalinity when the treatment period is ended.
6. The longer period of treatment with cyanide and cyanogen bromide, while slightly increasing the consumption of cyanide, also gives a material increase in extraction.
7. For treatment with cyanide and cyanogen bromide, a 0.148 per cent. cyanide solution yields as good an extraction, if not better, than either of the other two solutions, and the cyanide consumption is practically no greater than when a 0.099 per cent. cyanide solution is used.
8. The cyanide consumption increases considerably when using the strong solution for bromocyanidation.
9. Under correct treatment conditions, i.e., a 0.148 per cent. cyanide solution and treatment for a total period of five hours in a solution showing no protective alkalinity, an extraction of ninety per cent. of the gold can be expected.

EFFECT OF AMALGAMATION BEFORE BROMOCYANIDATION.

Since, in the bromocyanidation of this ore, it has not been found possible, under the short period conditions of treatment, to secure extractions exceeding ninety per cent. of the gold, it is possible that amalgamation to extract that portion of the gold which is too coarse to dissolve during the comparatively short time of treatment may result in an improved extraction. To determine whether amalgamation is necessary in the case of this particular ore, a sample, assaying 11.1 dwt. gold per ton, was amalgamated during fine grinding in the pebble mill, the residue after amalgamation assaying 10.1 dwt. gold per ton, representing an extraction of 1 dwt. gold per ton, or 9.01 per cent. Four tests were then carried out on this amalgamated product under varying conditions as regards time of agitation and alkalinity, or acidity, of the solution during treatment. The results of these tests show that by combined amalgamation and bromocyanidation under correct solution conditions, i.e., a slightly acid solution, a total extraction of only eighty five per cent. of the gold is possible and that no advantage was gained by increasing the total time of treatment from three to five hours, although, as might be expected, the longer time of treatment resulted in a higher consumption of cyanide. The treatment conditions and the results of these tests are shown in the following table.

EFFECT OF AMALGAMATION BEFORE BROMOCYANIDATION.

Golden Horseshoe Ore - Assay value: Before amalgamation, 11.1 dwt./ton
 After amalgamation, 10.1 dwt./ton
 Extraction, 1.0 dwt. Au per ton = 9.01 per cent.
 Treatment conditions : Pulp ratio, 1 : 1.
 Cyanide solution, 0.148 per cent. KCN
 CNBr added, 1 lb. per ton of ore.

Test No.	250	251	252	253
Initial CaO added, lb. per ton	-	2	-	2
Agitation time, hours (With KCN)	2	2	3	3
(With CNBr)	1	1	2	2
Pregnant solution (KCN, per cent.)	0.097	0.134	0.083	0.129
(KCN+HCN, per cent.)	0.107	-	0.103	-
(CNBr, per cent.)	0.018	0.009	0.018	0.021
(CaO, per cent.)	-0.0065	0.015	-0.008	0.014
KCN Consumption (Apparent)	1.06	-	1.34	-
lb. per ton (Actual)	0.86	0.32	0.94	0.42
Residue, dwt. Au per ton	1.6	4.8	1.6	5.0
Extraction, per cent.	84.16	52.47	84.16	50.49
Extraction by amalgn., per cent.	9.01	9.01	9.01	9.01
Extraction by cyanidn., per cent.	76.57	47.75	76.57	45.94
Total extraction, per cent.	85.58	56.76	85.58	54.95

It follows, therefore, that the cause of the low extraction obtained when amalgamation is not practised is not due to the presence of slowly dissolving coarse gold, and the cause of the failure to obtain extractions of over ninety per cent. must be sought elsewhere. It therefore becomes a question of ascertaining which particular gold-bearing constituent of the ore resists dissolution during the short periods of treatment with cyanide and cyanogen bromide.

It is apparent that, whether amalgamation is or is not practised, the maximum extraction obtainable by short treatment with cyanide and cyanogen bromide is under ninety per cent., and, as amalgamation does not improve the extraction, it follows that the low result is due either to inability to dissolve the gold combined in the tellurides or to some peculiarity of the intimate association of gold with the pyrite that renders its extraction impossible without resorting to oxidation of the pyrite by roasting and thus liberating the gold from the sulphide. In the course of a large number of investigations into the treatment of auriferous pyritic ores from various parts of Western Australia it has been found that, with two exceptions, every ore has been readily amenable to direct cyanidation without roasting. The two exceptions have been ore from Wiluna in which the gold is associated for the most part with arsenopyrite (approximately 1 dwt. gold to 0.1 per cent. arsenic), and the Kalgoorlie ores in which the gold occurs in the free state, as tellurides of gold, and in intimate association with pyrite. Hence it is reasonable to conclude that unless the pyrite of Kalgoorlie differs radically from the pyrite from all other parts of the State, the interfering constituent is not the pyrite but the telluride of gold.

SEPARATION OF TELLURIDE FROM PYRITE.

When experimental work on the flotation of the Kalgoorlie sulpho-telluride ores was commenced in this laboratory in 1923 it was found that a small quantity of a high grade concentrate could be readily obtained without flotation of the whole of the pyrite, but that unless the whole of the pyrite was also floated it was impossible to obtain a low grade residue by flotation. This experimental work was carried out before the introduction of potassium xanthate as a flotation reagent, but, with the employment of this reagent and suitable combinations of oils, successful flotation became possible.

This possibility of producing a high grade concentrate without flotation of the pyrite leads to the conclusion that this rich concentrate contains the fine free gold and the tellurides of gold occurring in the ore, since tellurides of gold are readily floated by violent agitation and aeration of the ore pulp, even without the use of frothers or collecting agents. If, therefore, it be possible, by suitable flotation methods, to remove from the ore the tellurides, from which it is recognised as being impossible to make a satisfactory extraction of the gold by direct treatment with cyanide alone without roasting or the use of cyanogen bromide, it is probable that in this way a large proportion of the gold may be concentrated in a small quantity of rich telluride concentrate to be subsequently treated by special methods (bromocyanidation or roasting and cyanidation), and that treatment of the flotation residue by agitation with plain cyanide solution may yield a satisfactory extraction of the gold from this portion of the ore, containing pyrite but no telluride. Flotation of tellurides of gold has been shown to be comparatively easy, while the flotation of pyrite is much more difficult. At the same time it is possible, during flotation of complex sulphide ores, to prevent, either partially or completely, the flotation of pyrite by the use of suitable depressants. These depressants of pyrite apparently prevent the flotation of the mineral by forming, as a result of chemical reactions between the depressant and the pyrite, a film of some oxidation or other product which renders the sulphide unable to attach itself to the oil film of the flotation froth. Among the better known reagents used for depressing pyrite during flotation are lime, potassium or sodium cyanide, and oxidising agents such as potassium or sodium dichromate and permanganate, all of which appear to produce a film of oxide on the surface of the pyrite grains, which prevents their flotation.

In the flotation of a gold ore the use of alkali cyanides as depressants of pyrite is not advisable on account of the solvent action that would take place during the milling and flotation, with the consequent necessity of precipitating large quantities of very weak cyanide solution to recover the dissolved gold. Therefore some other inhibitor of flotation of pyrite must be employed which will serve the same purpose while not exercising a solvent action on the gold. Of the oxidising agents likely to be of use in this connection, the dichromates and permanganates of the alkali metals appear to offer decided advantages over the cyanides because of their relatively great oxidising power. It has been found, however, that the addition of small quantities of tannic acid, of the order of a few tenths of a pound per ton of ore, is capable of preventing, more or less completely, the flotation of pyrite, even when potassium xanthate is used in conjunction with the oils and tannic acid. The action of the tannic acid in preventing flotation of the pyrite may be due to

1. Reaction between the acid and the oil to form esters.
2. Formation of coatings of insoluble tannates on the surface of the pyrite.
3. Destruction of xanthate.

In view of the advantage that would appear to accrue if, by some simple treatment, it were possible to remove for subsequent special treatment the small quantity of tellurides, and then to obtain a satisfactory extraction of the gold associated with the pyrite by simple cyanidation, a trial of this method of treatment has been made for the purpose of securing information which might serve as a guide for future investigation of the possibilities of this method of attacking the problem of the economical treatment of these ores. Direct cyanidation tests, without the use of cyanogen bromide, on these ores have shown that extractions of sixty per cent., and over, of the gold are possible in this way, so that it is highly probable that the major portion of the gold which is not extractable by plain cyanide is contained in the more difficultly attacked tellurides, and that the increased extraction obtained by the addition of cyanogen bromide after

agitation with plain cyanide solution is due to the action of this reagent and the cyanide on the telluride minerals.

In the preliminary flotation test, details of which are given below, crude eucalyptus oil was used as the collector and frother, while tannic acid was used as an inhibitor of the flotation of pyrite. Flotation was carried out in salt water (5 per cent. concentration of sodium chloride), since it has been abundantly proved that in the flotation of Kalgoorlie ores salt water is necessary for the production of a clean high grade concentrate and a low grade residue. The ore was ground dry to pass an 8 mesh I.M.M. screen and finally ground wet in a pebble mill in salt water with the oil and tannic acid, the addition of the necessary reagents to the grinding charge having been found to yield more satisfactory results than addition to the flotation machine. This grinding operation produced a minus 200 mesh product which was floated in a Ruth sub-aeration laboratory machine without the addition of any further reagents. During the flotation the pyrite showed no tendency to float and the froth, instead of having a metallic appearance, was dark grey and showed no sign of pyrite. The removal of froth was conducted so as to obtain sufficient concentrate for subsequent assays and determination. The conditions and the result of this flotation test are as follows :-

FLOTATION OF TELLURIDE.

Flotation charge : Pulp ratio, 1 : 5.
 Eucalyptus oil, 0.5 lb. per ton
 Tannic acid, 0.33 lb. per ton
 Salt water, 5 per cent. NaCl.

Flotation time : 5 minutes.

Test No.	Head Assay		Product	Weight per cent.	Assay value		Distribution, per cent.	
	dwt. Au per ton (calcd)	Sulphur per cent.			dwt. Au per ton	Sulphur per cent.	Gold	Sulphur
243	15.175	2.4	Concentrate	11.08	93.6	2.45	68.36	11.31
			Residue	88.92	5.4	2.39	31.64	88.69

This result shows that it is possible to extract in this way a large proportion of the gold in the form of a high grade concentrate without concentration of the pyrite in the froth.

CYANIDATION OF PYRITIC FLOTATION RESIDUE.

To determine whether it is possible to obtain a high percentage extraction from this flotation residue by agitation with plain cyanide solution, two preliminary tests were carried out in which the residue was agitated for eighteen hours in a 1 : 1 pulp with a 0.148 per cent. cyanide solution, with the addition of 4 lb. CaO per ton of ore. The treatment conditions and the results of these tests are shown in the following table.

CYANIDATION OF PYRITIC FLOTATION RESIDUE.

Treatment conditions : Assay value of residue, 5.4 dwt. Au per ton
 Pulp ratio, 1 : 1
 CaO addition, 4 lb. per ton
 Cyanide solution, 0.148 per cent. KCN
 Agitation time, 18 hours.

Test No.		244	245
Pregnant solution, {	KCN, per cent.	0.101	0.101
	CaO, per cent.	0.058	0.056
KCN Consumption, lb. per ton		0.90	0.90
CaO Consumption, lb. per ton		2.84	2.88
Residue, dwt. Au per ton		1.0	1.7
Extraction, per cent.		81.48	68.52

The alkalinity of the pregnant solution is too high and the consumption of lime indicates that 3 lb. CaO per ton of residue would be sufficient.

FLOTATION OF TELLURIDE - EFFECT OF DEPRESSANTS.

The effect of different depressants of pyrite was determined in a further series of tests on Golden Horseshoe ore under the following constant conditions, all reagents being added to the pebble mill charge during fine grinding. The results are shown in the following table.

FLOTATION OF TELLURIDE.EFFECT OF DEPRESSANTS.

Flotation conditions : Flotation pulp ratio, 1 : 3
 Salt water, 5 per cent. NaCl
 Eucalyptus oil, 0.5 lb. per ton
 Flotation time, 5 minutes.

Test No.	Depressant		Head Assay		Product	Wt., per cent.	Assay value		Distribution, per cent.	
	Descriptn.	Wt., lb. per ton	dwt. Au per ton (calc)	S, per cent.			Au, dwt. per ton	S, per cent.	Gold	Sulphur
246	-	-	14.05	2.4	Conct. Residue	15.97 84.03	62.2 4.9	3.30 2.23	70.70 29.30	21.96 78.04
247 6	Potassium dichrom.	0.5	14.54	2.4	Conct. Residue	16.08 83.92	66.4 4.6	2.57 2.37	73.45 26.55	17.22 82.78
248	Tannic acid	0.33	13.0	2.4	Conct. Residue	14.95 85.05	66.4 3.6	2.68 2.36	76.36 23.64	16.27 83.73
249	Lime	1.0	13.54	2.4	Conct. Residue	33.1 66.9	31.2 4.8	2.09 2.55	76.28 23.72	28.82 71.18

Except when tannic acid was used, the froth was very "wild" and especially so when lime was used, the froth in this case being quite uncontrollable, which is shown by the percentage weight and the assay value of the concentrate.

As the object in these flotation tests was to remove the telluride as completely as possible without at the same time floating the pyrite, heavy skimming of the flotation charge was practised, which

accounts for the high percentage of concentrate in each test. At the same time, it was noticeable that the pyrite showed very little tendency to float, even when no depressant was employed. The use of lime as a depressant resulted in the formation of an uncontrollable froth, very much lighter in colour than those obtained in the other tests.

The concentrates from these flotation tests all gave distinct reactions for tellurium when tested with sodium amalgam, while a similar test applied to the residues, gave in each case a negative result. Therefore, this method of flotation enables a complete separation of the tellurides to be made, with a consequent very considerable lowering of the grade of the ore.

Sulphur determinations on the products show that the concentrates contain practically the same percentage of sulphur as the original ore, and consequently no concentration of pyrite in the telluride concentrate has taken place. The percentage recovery of sulphur in the concentrates is but little greater than the percentage weight of the concentrates, except in Test 249, where the percentage of concentrate is abnormal owing to the use of lime as a depressant of the pyrite. Microscopic examination of the concentrates reveals the presence of free gold, tellurides and a very small quantity of pyrite, probably floated by entanglement in the telluride froth.

FLOTATION OF TELLURIDES.

Since, in the previous flotation tests for the purpose of concentrating free gold and tellurides, the quantity of concentrates was very large in comparison with the amount of telluride present in the ore, further flotation tests were performed to ascertain whether it was possible to obtain a similar concentration with a low grade flotation residue by taking off a small proportion of concentrate. For these tests samples of Boulder Perseverance ore were used, and in two tests depressants were employed, viz., tannic acid and an infusion prepared from the leaves of a shrub which has been locally used with success for tanning purposes. In a third test no oils or reagents were used and the frothing of the ore pulp itself, produced by the violent agitation and aeration in the flotation machine and by the presence in the ore of considerable quantities of calcite - a characteristic of the Kalgoorlie ores - was depended upon to bring about the necessary flotation of the tellurides. All three tests showed that it was possible to produce a small percentage of high grade concentrate and that the proportion of pyrite that floated with the concentrate was largely dependent on the quantity of concentrate produced, or, in other words, flotation of the pyrite was due, not to any inherent tendency of the pyrite to float but rather to mechanical inclusion in the flocculated masses of calcite and tellurides and that the quantity of pyrite floated was very nearly proportional to the weight of concentrate removed.

Test 256, in which no reagent other than salt water was used, showed practically similar results to those of Test 254 in which eucalyptus oil was used as a frother and collector and tannic acid was used as a depressant of pyrite.

The grade of the flotation residues is somewhat higher than in the previous tests in which a large quantity of concentrate was produced, but this is no doubt due to the flotation of less of the auriferous pyrite.

The flotation conditions and the results of these tests are shown in the following table.

FLOTATION OF TELLURIDES.

Flotation conditions : Pulp ratio, 1 : 5.

Salt water, 5 per cent. NaCl.

Flotation time, 5 minutes.

Reagents used: Test 254- Tannic acid, 0.33 lb. per ton;

Eucalyptus oil, 0.2 lb. per ton.

Test 255- Tan liquor, 10 c.c.; Eucalyptus oil,
0.2 lb. per ton.

Test 256- Nil.

Test No.	Head assay		Products	Wt., per cent.	Assay value		Distribution, per cent.	
	Au, dwt. per ton	S, per cent.			Au, dwt. per ton	S, per cent.	Gold	Sulphur
254	14.0	3.05	Concentrate	4.6	180.0	2.35	59.12	3.54
			Residue	95.4	6.0	3.08	40.88	96.46
255	15.4	3.05	Concentrate	5.68	154.4	3.29	57.05	6.12
			Residue	94.32	7.0	2.86	42.95	93.88
256	16.4	3.05	Concentrate	5.32	180.8	2.62	58.85	4.57
			Residue	94.68	7.1	3.08	41.15	95.43

CYANIDATION OF FLOTATION RESIDUES.

Cyanide tests were carried out on these residues by agitation for periods varying from twelve to thirty six hours with a 0.145 per cent. cyanide solution and three pounds of lime per ton of ore, this proportion of lime having been found in Tests 244 and 245 to be sufficient to produce protective alkalinity in the pregnant solution when treating similar residues. The cyanide consumption in these tests is exceedingly low and the protective alkalinity of the pregnant solution is sufficiently high for efficient precipitation. The treatment conditions and the results of these tests are shown in the following table.

CYANIDATION OF FLOTATION RESIDUES.

Treatment conditions : Pulp ratio, 1 : 1.

Barren solution, 0.145 per cent. KCN.

CaO added, 3 lb. per ton of ore.

Test No.	257	258	259	260
Flotation residue from Test	254	254	255	256
Flotation residue, assay value, dwt.				
Au per ton	6.0	6.0	7.0	7.1
Agitation time, hours	12	24	30	36
Pregnant solution (KCN, per cent.	0.133	0.128	0.131	0.126
(CaO, per cent.	0.021	0.023	0.025	0.024
Consumption, lb. per ton (KCN	0.24	0.34	0.28	0.38
(CaO	2.59	2.54	2.50	2.52
Cyanide residue, assay value, dwt.				
Au per ton	1.2	0.8	1.0	0.9
Extraction, per cent.	80.00	86.66	85.77	87.32

These tests indicate that these residues, resulting from the flotation of the tellurides, are readily amenable to treatment with cyanide alone and that, in consequence, the cause of the difficulty in the treatment of these ores with cyanide alone is the presence of the small quantity of tellurides from which the gold is not readily recoverable by simple cyanide treatment.

In order to prepare samples of telluride concentrates and of

residues on which to carry out tests to determine the possibilities of cyanidation and bromocyanidation of the two products, a series of flotation tests was carried out on Boulder Perseverance ore, assaying 15.6 dwt. gold per ton, the flotation conditions and the result being as shown below.

FLOTATION OF TELLURIDE.

Flotation conditions : Pulp ratio, 1 : 5.
Flotation in 5 per cent. NaCl solution.
No reagents used.
Flotation time, 5 minutes.

Test No.	Head assay		Products	Wt., per cent.	Assay value		Distribution, per cent.	
	Au, dwt. per ton	S, per cent.			Au, dwt. per ton	S, per cent.	Au	S
261	15.6	3.05	Concentrate	11.0	94.0	3.23	66.32	11.48
			Residue	89.0	5.9	3.02	33.68	88.52

A moderately heavy skimming was made during flotation so that sufficient concentrate might be obtained for subsequent testing.

For the purpose of determining the concentration of cyanide solution necessary for treatment of the residues from this flotation, and the approximate time of treatment, two tests were carried out on these residues in which all treatment conditions were the same, except the concentration of the cyanide solution. The treatment conditions and the results of these tests are shown below.

CYANIDATION OF FLOTATION RESIDUE.

Treatment conditions : Pulp ratio, 1 : 1.
CaO added, 3 lb. per ton of ore.
Agitation time, 24 hours.

Test No.	262	263
Barren solution, KCN per cent.	0.100	0.148
Pregnant solution (KCN, per cent.)	0.083	0.123
(CaO, per cent.)	0.019	0.020
Consumption, lb. per ton (KCN)	0.34	0.50
(CaO)	2.62	2.60
Flotation residue value, dwt. Au per ton	5.9	5.9
Cyanidation residue, dwt. Au per ton	1.2	1.0
Extraction, per cent.	79.66	83.05

These tests show that, as in previous similar tests, three pounds of lime per ton of ore produces protective alkalinity sufficient for precipitation, in the solution after treatment and that the cyanide consumption which is low in both tests, increases with the concentration of the cyanide solution.

The results show that the stronger cyanide solution gives a better extraction, although at the same time the cyanide consumption is slightly increased, and that a longer period of agitation than twenty four hours is advisable to secure the maximum extraction.

BROMOCYANIDATION OF TELLURIDE CONCENTRATE.

In order to obtain information regarding the conditions under which bromocyanidation of the telluride concentrate should be carried out, two tests were performed on the concentrate from Test 261 by agitating for eighteen hours with a 0.257 per cent. cyanide solution, without addition of lime, and subsequent addition of cyanogen bromide.

In Test 264, the whole of the cyanogen bromide, 2 lb. per ton of concentrates, was added after eighteen hours' agitation with the cyanide solution, while in Test 265 the cyanogen bromide was added in two equal portions of 1 lb. per ton of concentrates after eighteen and twenty one hours' agitation. In each case the consumption of cyanide was high and the pregnant solution was acid, while only 60 - 67 per cent. of the cyanogen bromide had been destroyed during the treatment, indicating that the period of agitation after addition of cyanogen bromide had not been sufficiently prolonged to enable the full effect of the reagent to be obtained.

The treatment conditions and the results of these tests are shown in the following table.

BROMOCYANIDATION OF TELLURIDE CONCENTRATE.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.257 per cent. KCN.

Test No.	264	265			
Agitation time, hours (With KCN)	18	18			
(With CNBr)	6	6			
CNBr added, lb. per ton	4	4			
Pregnant solution	{	KCN, per cent.	0.064	0.060	
			KCN+HCN, per cent.	0.090	0.086
				CNBr, per cent.	0.0414
			CaO, per cent.	-0.024	-0.024
KCN Consumption, lb. per ton	{	Apparent	3.86	3.94	
		Actual	3.34	3.42	
Head value, dwt. Au per ton	94.0	94.0			
Residue value, dwt. Au per ton	14.4	15.6			
Extraction, per cent.	84.32	83.05			

In consequence of the high percentage of residual cyanogen bromide at the conclusion of these two tests, a further test was carried out on the same concentrate in which agitation with cyanide solution was continued for twenty four hours, after which cyanogen bromide in the proportion of four pounds per ton of concentrates was added to the pulp and agitation continued for a further period of twelve hours. At the conclusion of this test the pregnant solution was acid and the whole of the cyanogen bromide had been decomposed. The treatment conditions and the result of this test are as follows :-

BROMOCYANIDATION OF TELLURIDE CONCENTRATE.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.257 per cent. KCN.
Agitation time, hours (With KCN, 24
(With CNBr, 12.
CNBr added, 4 lb. per ton of concentrates.

Test No.	270		
Pregnant solution	{	KCN, per cent.	0.026
		KCN+HCN, per cent.	0.066
		CNBr, per cent.	0.0
		CaO, per cent.	-0.026
KCN Consumption	{	Apparent	4.62
		Actual	3.82
Head value, dwt. Au per ton	94.0		
Residue value, dwt. Au per ton	6.2		
Extraction, per cent.	93.40		

CYANIDATION OF FLOTATION RESIDUES.

The results of Tests 262 and 263, in which the residues from the flotation of the tellurides were cyanided for twenty four hours with cyanide solutions of different concentrations, indicated that a longer agitation period with the stronger solution might yield a still lower

grade residue. Therefore, further tests were carried out on the same residue under similar conditions to those obtaining in Test 263, except that the treatment period was increased to forty eight and fifty four hours. The treatment conditions and the results of these tests are as follows :-

CYANIDATION OF FLOTATION RESIDUES.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.148 per cent. KCN.
CaO added, 3 lb. per ton of residue.

Test No.	266	267	268	269
Agitation time, hours	48	48	54	54
Pregnant solution { KCN, per cent.	0.127	0.127	0.126	0.126
	0.017	0.013	0.016	0.016
Consumption, lb. per ton { KCN	0.42	0.42	0.44	0.44
	2.66	2.74	2.68	2.68
Flotation residue, dwt. Au per ton	5.9	5.9	5.9	5.9
Cyanidation residue, dwt. Au per ton	0.9	0.7	0.75	0.7
Extraction, per cent.	84.74	88.14	87.29	88.14

Combining the results of Tests 261, 267, and 270 gives the following total extraction by flotation and separate cyanidation and bromocyanidation, respectively, of the flotation residue and concentrates, extractions being expressed as percentages of the gold contained in the original ore before flotation.

TOTAL EXTRACTIONS.

Extraction from telluride concentrate,	61.91 per cent.
Extraction from flotation residue,	29.67 per cent.
Total extraction by flotation, cyanidation and bromocyanidation	91.58 per cent.
Value of Combined residues, (11 per cent. flotation concentrate + 89 per cent. flotation residue)	1.305 dwt. Au per ton.
Extraction based on head and residue values	<u>91.63 per cent.</u>

Although these combined results are highly satisfactory and show that the two flotation products are capable of separate treatment, the grade of the residues from the bromocyanidation of the telluride concentrates is too high to enable them to be discarded, and therefore it is essential that means be devised to reduce the grade of these residues to an economic minimum. Since this concentrate contains free gold which dissolves very slowly in cyanide solution, it is possible that amalgamation of this concentrate before bromocyanidation may assist in obtaining the required reduction in grade. Consequently, as the supply of concentrates from Test 261 was exhausted, a bulk sample for amalgamation and bromocyanidation was prepared by mixing the concentrates from Tests 246, 247, 248, 249, 254, 255, and 256. This bulk sample, assaying 57.6 dwt. Au per ton, was then used for amalgamation and bromocyanidation tests.

AMALGAMATION OF TELLURIDE CONCENTRATES.

Portion of the bulk sample of telluride flotation concentrates was amalgamated by agitation with water and mercury without additional grinding, and, after removal of mercury and amalgam, the product was filtered and allowed to dry. The result of the amalgamation, which shows that the concentrates contain only a small proportion of the gold in an amalgamable form, was as follows :-

Value Before amalgamation,	57.6 dwt. Au per ton
Value After amalgamation,	52.8 dwt. Au per ton
Extraction by amalgamation,	4.8 dwt. Au per ton
	= 8.33 per cent.

CYANIDATION AND BROMOCYANIDATION OF AMALGAMATED TELLURIDE CONCENTRATES.

Comparative tests were carried out on the un-amalgamated and amalgamated telluride concentrates to determine whether the preliminary amalgamation enabled lower grade residues to be obtained by bromocyanidation, and also to demonstrate the impossibility of securing a satisfactory extraction by agitation with cyanide alone under the same conditions as were adopted for bromocyanidation. At the same time, a test was carried out on each product to determine the extraction obtained with cyanide alone up to the time of addition of the cyanogen bromide, and to show the accelerating solvent action of that reagent in conjunction with the cyanide. Since Test 270 had given an encouraging result, similar treatment conditions were adopted in the bromocyanidation tests, while in the tests with cyanide alone, agitation was carried out for twenty four hours without lime in one pair of tests and for thirty six hours with addition of three pounds of lime per ton of concentrates in the second pair of tests; the former pair indicated the extraction obtained under normal bromocyanidation conditions prior to the addition of cyanogen bromide, while the latter pair furnished a comparison between the results obtainable by treatment with cyanide alone with the necessary addition of lime and with cyanide and cyanogen bromide for the same total period.

On un-amalgamated concentrates the percentage extraction obtained by bromocyanidation is the same as in Test 270, although, as the grade of the concentrate is in this case lower, that of the residue is correspondingly lower. The consumption of cyanide, however, is slightly less on the lower grade concentrates, while the pregnant solution shows practically the same acidity as in Test 270.

On amalgamated concentrates, the extraction by bromocyanidation is greatly increased and the final residue is of reasonable grade, while the cyanide consumption is somewhat less than in the similar test on un-amalgamated concentrates.

Consequently, amalgamation is advisable to extract as much as possible of the slowly soluble free gold before bromocyanidation, and also enables a low grade residue to be produced.

The treatment conditions and the results of this comparative series of tests are shown in the following table.

CYANIDATION AND BROMOCYANIDATION OF UN-AMALGAMATED AND AMALGAMATED TELLURIDE CONCENTRATES.

Treatment conditions : Pulp ratio, 1 : 1.
Barren solution, 0.257 per cent. KCN.

Test No.	Un-amalgamated			Amalgamated		
	271	272	273	274	275	276
CaO added, lb. per ton	-	3	-	-	3	-
CNBr added, lb. per ton	-	-	4	-	-	4
Agitation (With KCN time, hours (With CNBr	24	36	24	24	36	24
Pregnant (KCN, per cent. solution (KCN+HCN, per cent.	0.150	0.132	0.068	0.154	0.154	0.094
(CNBr, per cent.	-	-	0.085	-	-	0.134
(CaO, per cent.	-	-	0.029	-	-	0.049
KCN Consumption (Apparent lb. per ton (Actual	0.002	0.028	-0.028	0.004	0.026	-0.018
Head value, dwt. Au per ton	2.14	2.50	3.76	2.06	2.06	3.26
Residue value, dwt. Au per ton	57.6	57.6	3.44	52.8	52.8	2.46
Extraction, per cent.	36.0	25.6	3.9	27.2	25.2	1.3
	37.50	55.55	93.23	44.54 48.48	52.27	97.54
Extraction by amalgamation	-	-	-	8.33	8.33	8.33
Extraction by cyanidation	37.50	55.55	93.23	48.48	47.91	89.41
Total extraction, per cent.	37.50	55.55	93.23	52.77	56.24	97.74

These tests prove conclusively that the telluride concentrate is amenable to treatment by amalgamation and bromocyanidation, with the production of a low grade residue, and that treatment with cyanide alone is incapable of yielding, within a reasonable time, a satisfactory extraction. Hence the flotation concentrate, produced without concentration of the pyrite, contains that portion of the auriferous minerals which are not readily attacked by cyanide alone, but which readily yield a high percentage of their gold content to treatment with cyanide and cyanogen bromide. The flotation residues have also been shown to contain the gold in a form in which it can readily be extracted by treatment with cyanide alone. Hence, selective flotation of the auriferous minerals enables two products to be made without difficulty and with no expense for flotation reagents, from both of which high percentage extractions can be obtained by suitable treatment with cyanide, and with cyanide and cyanogen bromide, respectively. The assay value of the total residue from the treatment of the two products may be expected to be under one dwt. gold per ton.

As these series of tests had exhausted the supply of telluride concentrates, a further quantity was obtained for confirmatory tests and further investigation by flotation of 7200 gram of the same ore in charges of 600 gram each, in a 1 : 5 pulp in a five per cent. salt solution, without flotation reagents, flotation of each charge being continued for five minutes and a fairly heavy skimming being made so as to obtain sufficient concentrates for testing purposes. It was shown in Test 256 that under similar conditions a small percentage of high grade concentrate could be produced, but, as larger quantities of concentrates are required for the necessary tests, the grade of the flotation concentrates has been sacrificed for the sake of obtaining a sufficient quantity for investigation. The result of this flotation is shown below.

FLOTATION OF TELLURIDES.

Test No.	Head Assay		Products	Wt., per cent.	Assay value		Distribution per cent.		Ratio of concentration
	dwt. Au per ton	S, per cent.			dwt. Au per ton	S, per cent.	Au	S	
277	15.5	9.20 3.16	Conct. Residue	8.19 91.81	107.2 7.3	2.69 3.20	56.71 43.29	6.98 93.02	11.48 : 1

The concentrate produced in Test 277 was used for a series of bromocyanidation tests under similar conditions to those of Tests 273 and 276 except that in Tests 280 and 281 the period of agitation after addition of cyanogen bromide was increased for the purpose of ascertaining whether a lower grade residue could be obtained in this way, rather than by increasing the quantity of cyanogen bromide, since in all tests except Test 270 the amount of undecomposed cyanogen bromide in the pregnant solution was comparatively high. For the tests on amalgamated concentrate, the amalgamation was carried out by agitation of the concentrate with water in an amalgamated copper pan. The amalgamation of the concentrate in this way gave the following result.

TEST 282. AMAIGAMATION OF TELLURIDE CONCENTRATE.

Value Before amalgamation, 107.2 dwt. Au per ton
 Value After amalgamation, 105.6 dwt. Au per ton
 Extraction by amalgamation, 1.6 dwt. Au per ton
 = 1.49 per cent.

As this was a new sample of concentrates, a thirty six hour test was carried out with cyanide alone, concurrently with the bromocyanidation tests, so as to enable the accelerating solvent action of the cyanogen bromide to be determined. The treatment conditions and the results of this series of tests are as follows :-

BROMOCYANIDATION OF TELLURIDE CONCENTRATE.

Treatment conditions , Pulp ratio, 1 : 1.
Barren solution, 0.256 per cent. KCN.

Test No.	Un-amalgamated Concentrate				Amalgamated Concentrate	
	278	279	280	281	285	286
CaO added, lb. per ton	3	-	-	-	-	-
CNBr added, lb. per ton	-	4	4	4	3	4
Agitation (With KCN	36	24	24	24	24	24
time, hrs. (With CNBr	-	12	15	18	12	12
Pregnant (KCN, per cent.	0.116	0.042	0.032	0.032	0.050	0.050
solution (KCN+HCN, per cent.	-	0.054	0.062	0.056	0.060	0.060
(CNBr, per cent.	-	0.0296	0.0286	0.0266	0.0197	0.0197
(CaO, per cent.	0.016	-0.026	-0.030	-0.028	-0.035	-0.035
KCN Consump- (Apparent	-	4.24	4.48	4.48	4.12	4.12
tion. lb./ton (Actual	2.80	4.04	3.88	4.00	3.92	3.92
Conct., dwt. Au per ton	107.2	107.2	107.2	107.2	105.6	105.6
Residue, dwt. Au per ton	63.8	7.0	8.6	6.6	14.0	6.4
Extraction, per cent.	40.48	93.47	91.98	93.84	86.74	93.94
<u>Total Extractions.</u>						
By amalgn., per cent.	-	-	-	-	1.49	1.49
By cyanidn., per cent.	40.48	93.47	91.98	93.84	85.44	92.54
Total, per cent.	40.48	93.47	91.98	93.84	86.93	94.03

These tests show that :

1. Treatment of the concentrate with cyanide alone gives a low percentage extraction in thirty six hours.
2. The addition of cyanogen bromide in the proportion of four pounds per ton of concentrate greatly accelerates the solution of the gold, and, although a high percentage extraction is obtained by continuing the agitation for from twelve to eighteen hours after addition of cyanogen bromide, the residues are of too high grade to be discarded.
3. Four pounds of cyanogen bromide per ton of concentrate gives a much greater extraction than three pounds per ton of concentrate, in the same time.
4. The extraction by amalgamation by the method adopted is very small and this method is much less efficient than agitation with mercury.
5. Cyanide consumption per ton of concentrate is in every case high, but, as the concentrate is only 8.19 per cent. of the ore, the cyanide consumption per ton of original ore is very low.

In order to make the treatment of the ore by flotation, cyanidation and bromocyanidation complete, the residues from Test 277, assaying 7.3 dwt. gold per ton, were agitated in a 1 : 1 pulp with 0.149 per cent. cyanide solution and 3 lb. lime per ton for forty eight hours, with the result shown in the following table.

CYANIDATION OF FLOTATION RESIDUES.

Treatment conditions : Pulp ratio, 1 : 1
 Barren solution, 0.149 per cent. KCN
 CaO added, 3 lb. per ton of residues
 Agitation time, 48 hours.

Test No.		283	284
Pregnant solution {	KCN, per cent.	0.086	0.083
	CaO, per cent.	0.018	0.019
Consumption, lb. per ton {	KCN	1.26	1.32
	CaO	2.64	2.62
Flotation residue, dwt. Au per ton		7.3	7.3
Cyanidation residue, dwt. Au per ton		1.2	1.1
Extraction, per cent.		83.56	84.93

In order to determine whether increased time of agitation of the same flotation residues under otherwise similar conditions of treatment would yield an increased extraction, duplicate tests were carried out in which the agitation time was increased to fifty five hours, with the result that the value of the cyanide residue was reduced to 0.9 dwt. Au per ton. The treatment conditions and the results of these tests are as follows :-

CYANIDATION OF FLOTATION RESIDUES.

Treatment conditions :- Pulp ratio, 1 : 1
 Barren solution, 0.149 per cent. KCN
 CaO added, 3 lb. per ton of residues
 Agitation time, 55 hours.

Test No.		287	288
Pregnant solution {	KCN, per cent.	0.081	0.083
	CaO, per cent.	0.019	0.028
Consumption, lb. per ton {	KCN	1.36	1.32
	CaO	2.62	2.44
Flotation residue, dwt. Au per ton		7.3	7.3
Cyanidation residue, dwt. Au per ton		0.9	0.9
Extraction, per cent.		87.67	87.67

The results of the combined treatment by flotation, amalgamation and bromocyanidation of the flotation concentrate, and cyanidation of the flotation residue are shown in the following tabulation, in which the results of the treatment of the concentrate and residue produced by flotation in Test 277 have been combined. The results of the cyanidation of the flotation residue are those shown in Tests 287 and 288, in which a final residue of 0.9 dwt. gold per ton was produced.

COMBINED TREATMENT OF FLOTATION CONCENTRATE AND RESIDUES.

Test No.	Extraction, per cent.			Total	Combined residue, dwt. Au per ton
	From concentrate		From residue		
	By Amalgn.	By Cyanidn.	By Cyanidn.		
278	-	22.96	41.35	64.31	6.05
279	-	53.01	41.35	94.36	1.40
280	-	52.16	41.35	93.41	1.53
281	-	53.22	41.35	94.57	1.37
285	0.84	48.46	41.35	89.81	1.97
286	0.84	52.48	41.35	93.83	1.35

Consideration of the combined results of the treatment of the two flotation products shows that although a comparatively high percentage extraction is obtained, the value of the combined residues is still too high and that very little further reduction in the grade of the total residues can be expected unless means can be devised by which the grade of the concentrates can be still further reduced by bromocyanidation. The principal factors, by the variation of which this result may be achieved, appear to be time of treatment and quantity of cyanogen bromide. The effect of increasing both time of treatment and quantity of cyanogen bromide and also of increasing the time of treatment of the flotation residues therefore requires investigation, but the results obtained by selective flotation and subsequent cyanidation and bromocyanidation have shown definitely that the gold in these ores exists in two states, one portion being extractable by cyanide alone, the other only by cyanide and cyanogen bromide.

Flotation of the tellurides and subsequent bromocyanidation of the telluride concentrate and plain cyanidation of the flotation residue serve to indicate that it is the small proportion of high grade telluride of gold which militates against obtaining a high percentage extraction from these ores by plain cyanide solution, but that this mineral can, for the most part, be removed by flotation without the addition of flotation reagents, utilising the frothing action of the calcite present in the ore, or by flotation with the addition of a frother and the use of a depressant to prevent flotation of pyrite. The tests also indicate the ready flotability of the gold tellurides in comparison with the pyrite, for the complete flotation of which the addition of a conditioning agent, such as potassium xanthate, is necessary. The results of the cyanidation tests on the flotation residues show that the gold associated with the pyrite can be readily extracted by plain cyanide solution, but, to obtain a satisfactory extraction of the gold from the telluride concentrate combined treatment with cyanide and cyanogen bromide is required.

Since these ores are always liable to contain coarse and fine free gold as well as gold combined in the tellurides and in association with pyrite, it is advisable, on account of the slow dissolution of the coarse gold by cyanide solution, to amalgamate the ore after or during fine grinding so as to extract and recover at the earliest possible moment and in the cheapest and simplest manner as much as possible of the gold content, instead of depending on the cyanide treatment to extract this portion of the gold. Therefore, in any scheme of treatment of these ores, amalgamation of the ore, either during fine grinding or by copper plate amalgamation after fine grinding in tube mills is advisable.

The selective flotation of the tellurides and the subsequent treatment of the concentrates and residues by separate and distinct methods were intended to furnish information as to the possibility of separating the non-amalgamable gold into two portions, viz.,

- (a) that combined in tellurides, and
- (b) that associated with pyrite,

and this separation has been shown to be possible. It has also been shown that by differentiating between these two classes of gold it is possible to make satisfactory extractions by bromocyanidation of the tellurides and plain cyanidation of the pyrite.

This method of treatment by flotation and separate treatment of the products is not put forward as a practicable scheme of treatment of the ore because any multiplication of processes tends to complicate the treatment and to increase treatment costs. At the same time, a primary flotation of

the tellurides without flotation reagents and a secondary flotation of the pyrite after addition of a frother such as eucalyptus oil and a conditioning agent such as potassium xanthate would, in the light of the experimental results obtained by the writer on the flotation of Kalgoorlie ores, enable two products to be obtained for subsequent treatment and a flotation residue of sufficiently low grade to be discarded without further treatment. These two products could then be treated separately either by bromocyanidation and plain cyanidation or by roasting and cyanidation of the roasted concentrates. If roasting and cyanidation were resorted to, there would be no benefit in producing two concentrates, but it would be more economical to produce one concentrate for subsequent bromocyanidation or roasting and cyanidation, instead of treating two classes of concentrate separately, so that duplication of cyanide plant would not be necessary.

The experimental work in this direction has, however, shown clearly the difference in the behaviour of the gold contained in the tellurides and in the pyrite and shows that cyanogen bromide is necessary only in the case of the tellurides, which do not yield a satisfactory extraction by plain cyanide solution.

METHODS OF TREATMENT.

For the treatment of Kalgoorlie sulphotelluride ores, and this applies to other refractory ores also, five methods of treatment are available and the principal factors affecting the determination of the most suitable process are as follows:-

- (1) Relative fineness of grinding required for each method, since very fine grinding adds greatly to the cost of treatment and to the cost of plant required.
- (2) Efficiency of the different methods, i.e., which yields the best commercial and economic extraction at the lowest cost and which requires the least skilled superintendence.
- (3) Simplicity of the plant required in each case, and therefore the relative capital cost of plants.
- (4) Tonnage capacities of plants on which the capital outlay is the same.
- (5) Power consumption for plants of the same tonnage capacity.

1. Fineness of Grinding.

There is very little difference in the final fineness to which the ore must be reduced for any one of the five processes, although the greatest fineness is probably necessary for straight-out bromocyanidation of the ore, followed by the flotation process, while the all-roasting process probably does not require such a fine product as any of the other processes. The cost of fine grinding will therefore be a maximum for straight-out bromocyanidation of the ore and it would be a minimum in the case of the all-roasting process if the grinding could be carried out in one operation. Unfortunately, however, the all-roasting process calls for a dry feed to the roasting furnaces and therefore the preliminary fine grinding must be carried out dry, with attendant disadvantages due to production of dust. After roasting, a secondary grinding operation is necessary to reduce the roasted ore to the fineness necessary to secure a maximum extraction of gold. Hence, in this process, two grinding sections, dry and wet, are necessary, with a consequent increase in capital cost, power consumption, expense of maintenance, repairs and superintendence. Therefore any of the all-wet treatment methods will be more suitable

from this aspect than the all-roasting process.

2. Efficiency of Processes.

In all probability the present all-roasting process calls for less skilled attention than does either of the other processes, while the straight-out bromocyanide process which, from experimental data, appears to be a process extremely susceptible to derangement by slight changes of treatment conditions, would require strict and close control to be exercised by a skilled metallurgist on each working shift.

A reliable comparison of the efficiencies of the different processes is impossible as the operating companies do not publish information regarding the percentage extractions or the treatment costs of the all-roasting process. At the same time, no plant is at present employing any of the other processes in its entirety, although experimental investigation has shown that the straight-out flotation process, employing roasting of the concentrates, should be capable of yielding as good an extraction of gold and as low, if not lower grade total residues than the existing process and at a very much lower cost of treatment. Lake View & Star Ltd. has recently installed a flotation unit treating 150 tons per day, which is giving good results but full figures are not available because the concentrate is at present being mixed with the ore for roasting. The extraction to be expected from straight-out bromocyanidation of the ore should, under favourable treatment conditions, reach 90 per cent., or even more, at a cost practically the same as that of the flotation process and the roasting process. Until, however, this process is actually put into operation, it will be impossible to state with any certainty what the extraction or cost of treatment is likely to be.

3. Simplicity of Plant and Capital Cost.

From this aspect, the bromocyanidation of the whole of the ore after fine grinding necessitates the simplest plant, consisting only of a wet grinding and agitation plant, and as the actual time of treatment is short, a comparatively small plant will have a large tonnage capacity.

For flotation followed by bromocyanidation of the flotation concentrate additional plant would be required for flotation of the ore, thus increasing the capital cost, although approximately only 12.5 per cent. of the ore would be treated by bromocyanidation after flotation, and therefore the necessary cyanide plant for treatment of large tonnages would be comparatively small.

Next in order comes concentration of the whole of the auriferous minerals into one product by flotation, and roasting and cyanidation of the concentrate, which would involve provision of roasting furnaces. The operation of the roasting furnaces would not involve a high consumption of fuel as the sulphur content of the concentrate is sufficient to provide the heat necessary to complete the roasting when once the charge has been raised to the temperature necessary to initiate oxidation of the pyrite and tellurides. The cost of roasting would probably not exceed the cost of the cyanogen bromide used in the bromocyanidation of the raw flotation concentrate, and therefore the only additional cost in this method of treatment would be the capital cost of the plant for filtration, drying and roasting of the concentrate together with the cost of maintenance of this section of the plant.

Any process in which two flotations were

performed for concentration of tellurides and sulphides separately, and the subsequent treatment of these products in separate units by bromocyanidation and plain cyanidation, respectively, would involve duplication of flotation plants, thickeners, and cyanidation equipment, thus adding materially not only to the cost of equipment but also to the cost of operation. Such a method of treatment, involving separate treatment of two products is not warranted where similar results can be obtained by the treatment of one concentrate as a whole.

Lastly, the all-roasting and cyanidation process at present in use, although efficient, suffers from the serious disadvantage that the whole of the ore has to pass through all stages of the treatment process and therefore the capital cost of roasting furnaces and cyanidation equipment as well as the cost of operation and maintenance are extremely high on account of the large plant necessary to handle large tonnages.

4. Tonnage Capacities of Plants.

On account of the simplicity of the method of treatment and the plant required, a plant for bromocyanidation of the whole of the ore can handle greater tonnages than a plant of the same cost designed for treatment by any of the other processes.

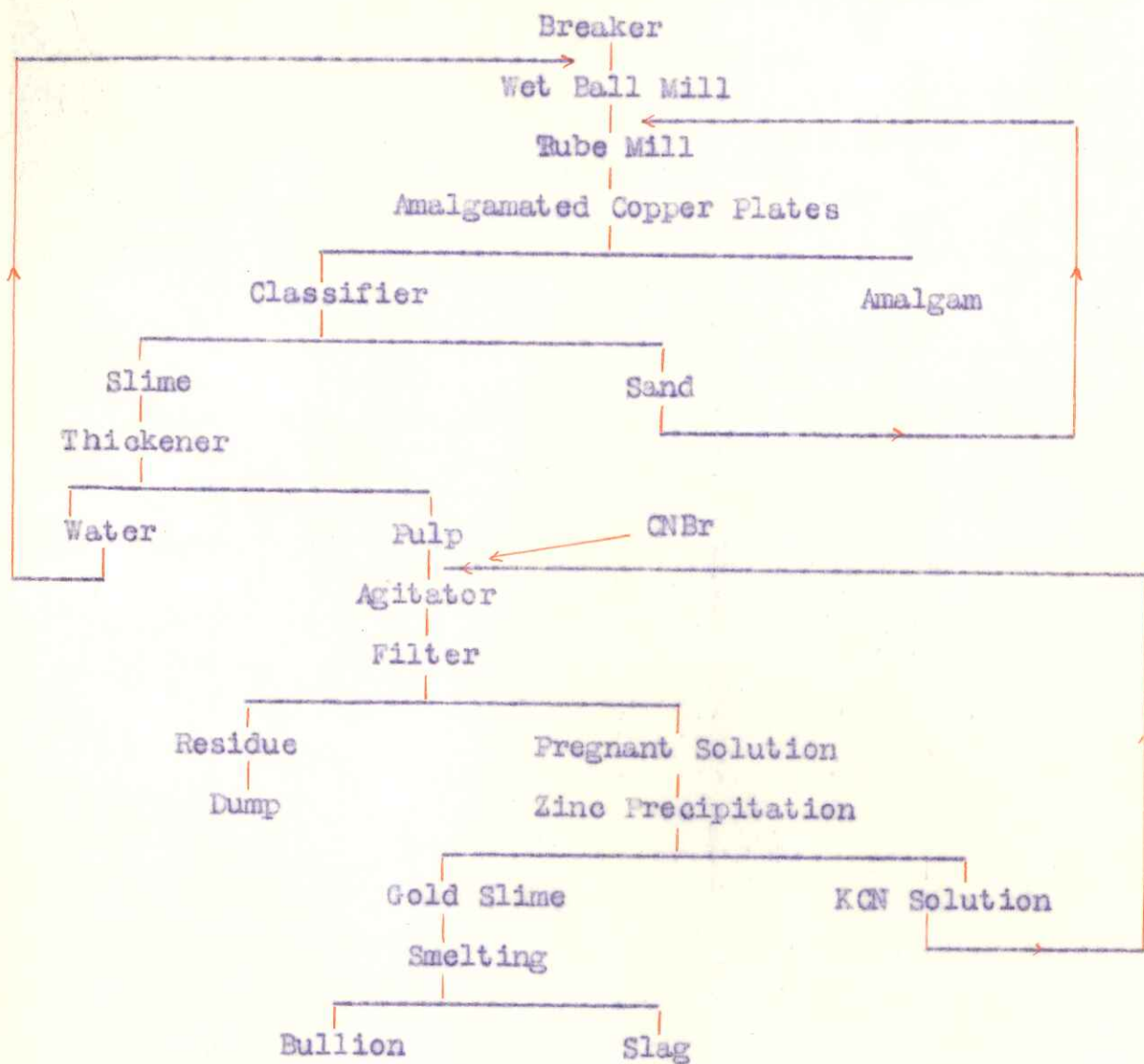
5. Power Consumption.

Bromocyanidation of the whole of the ore excels in this direction also, since, in addition to the power required in the grinding section of the mill which would be common to all the processes, the only additional power is that required for the agitation of the ore with the treatment solution.

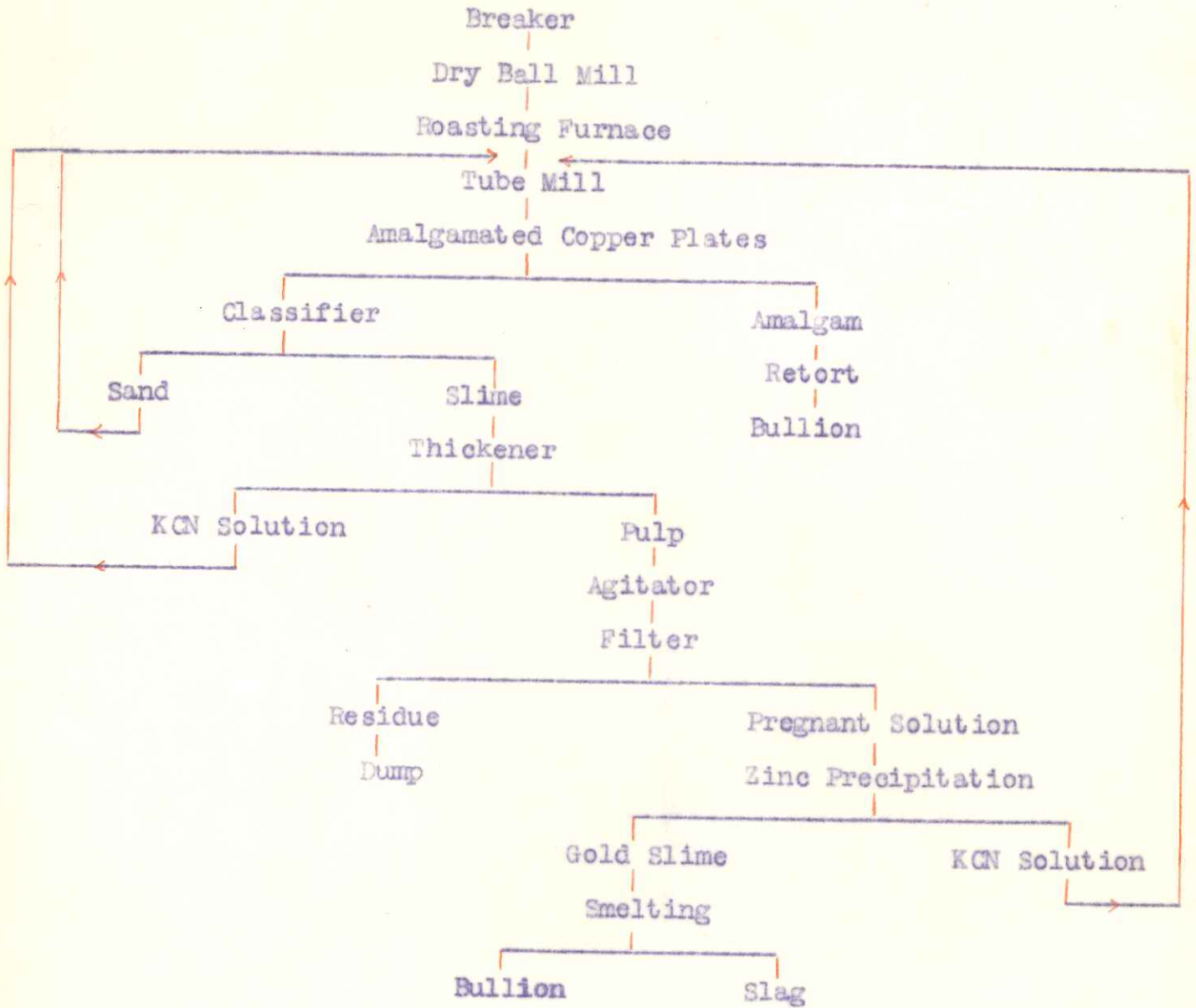
For the purpose of comparison, flow sheets of the five possible processes are given .

FLOW SHEETS.

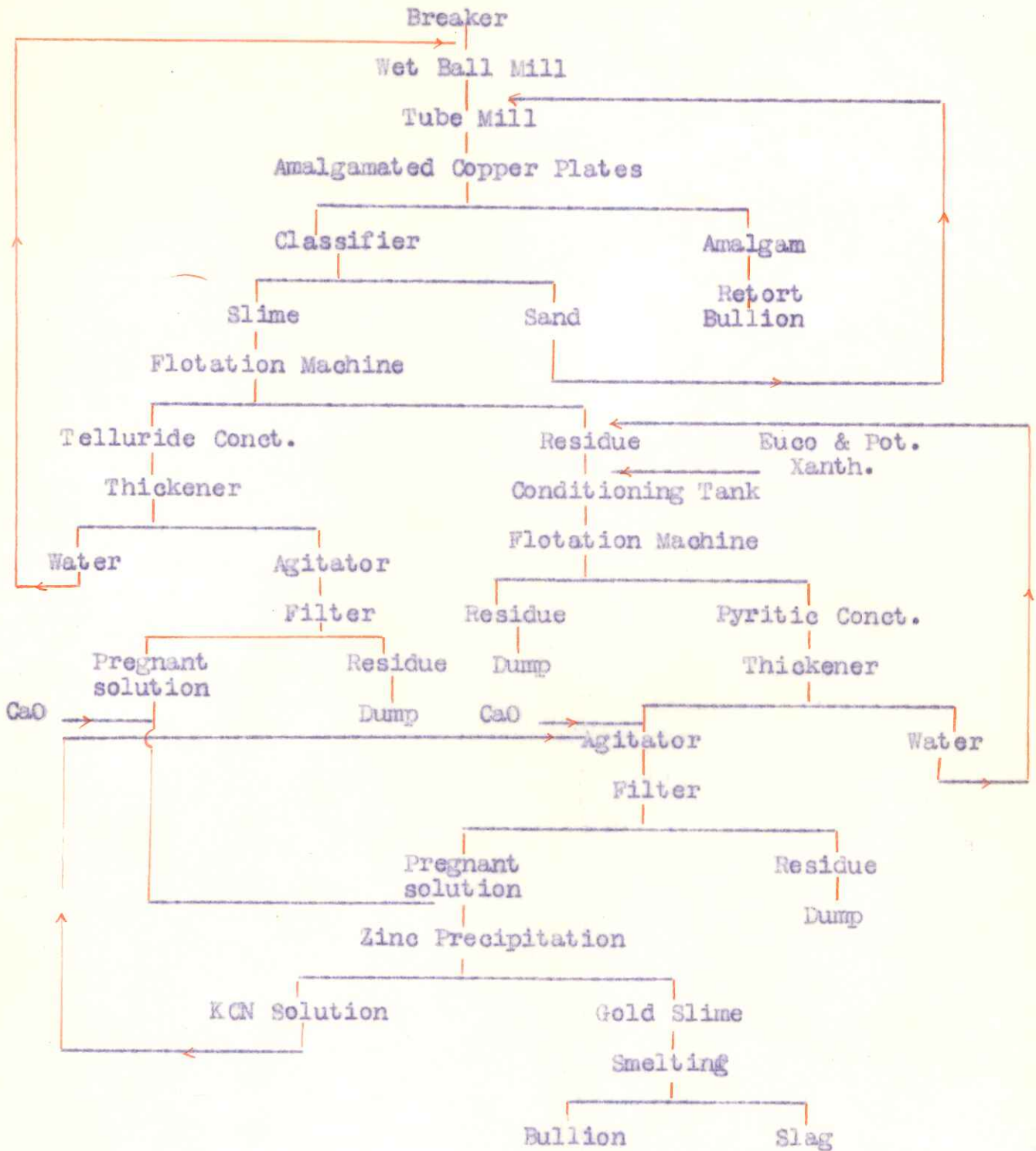
1. BROMOCYANIDATION OF THE WHOLE OF THE ORE.



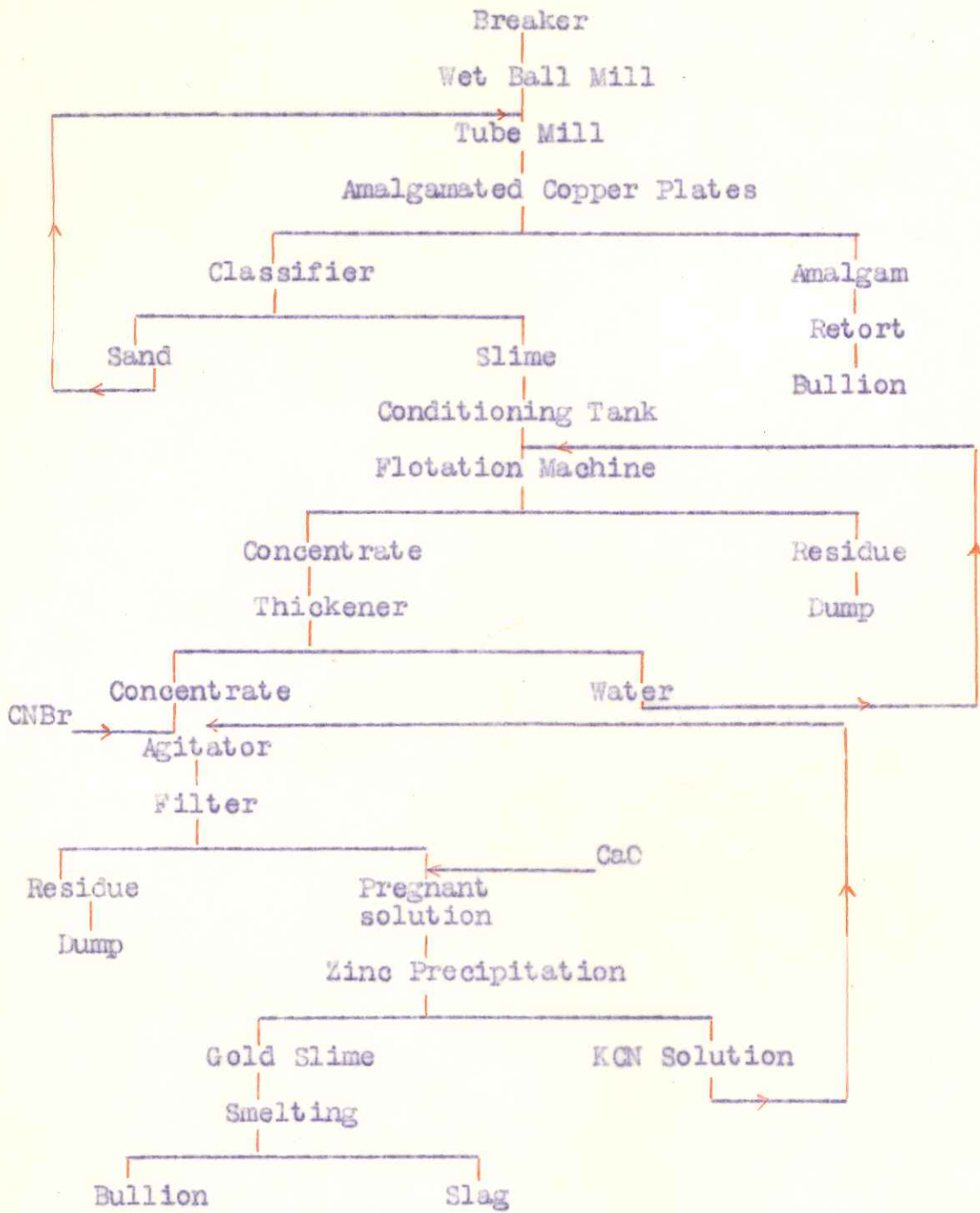
2. ALL-ROASTING AND CYANIDATION OF ORE.



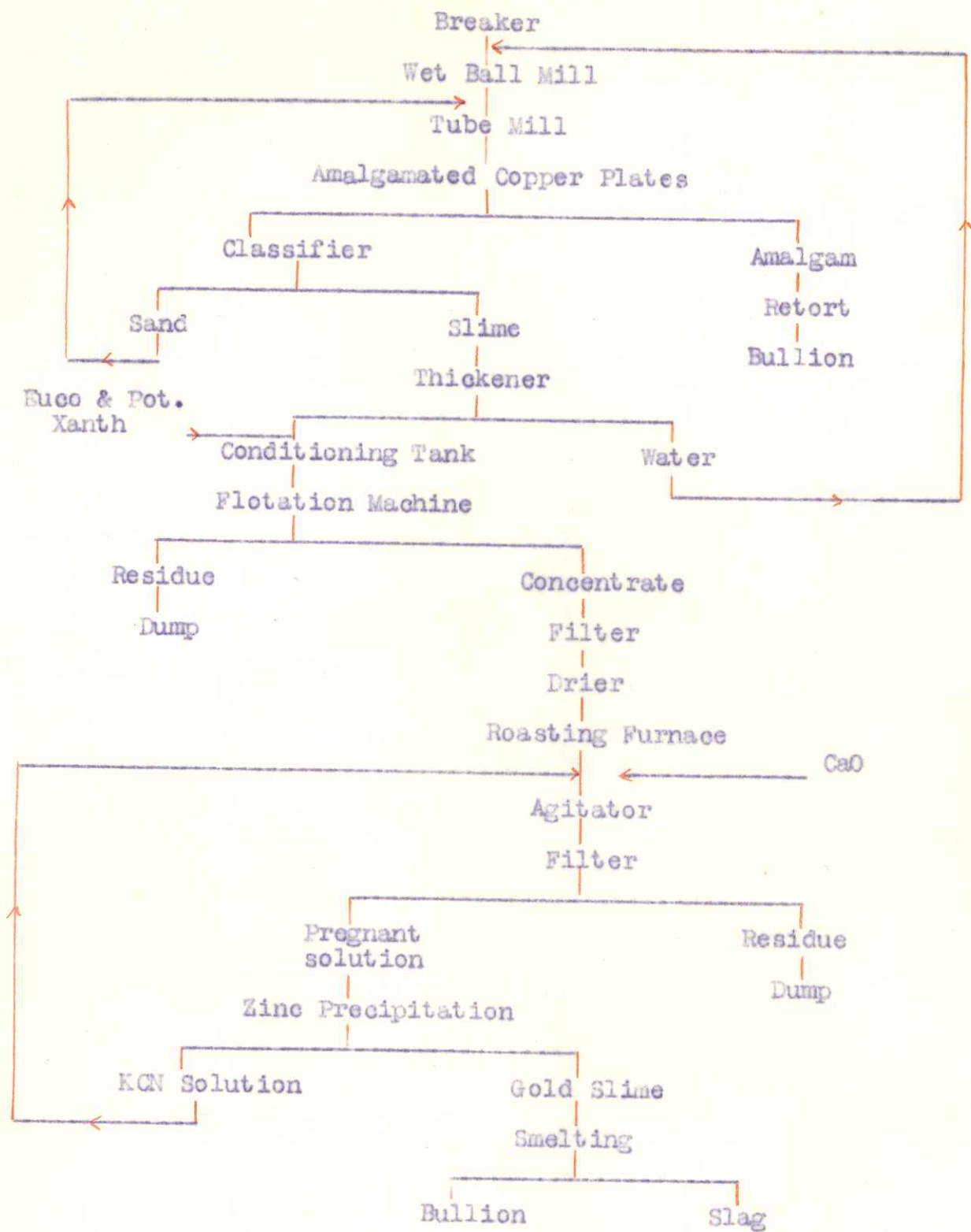
3. SEPARATE FLOTATION OF AURIFEROUS MINERALS AND TREATMENT OF CONCENTRATES BY BROMOCYANIDATION AND CYANIDATION.



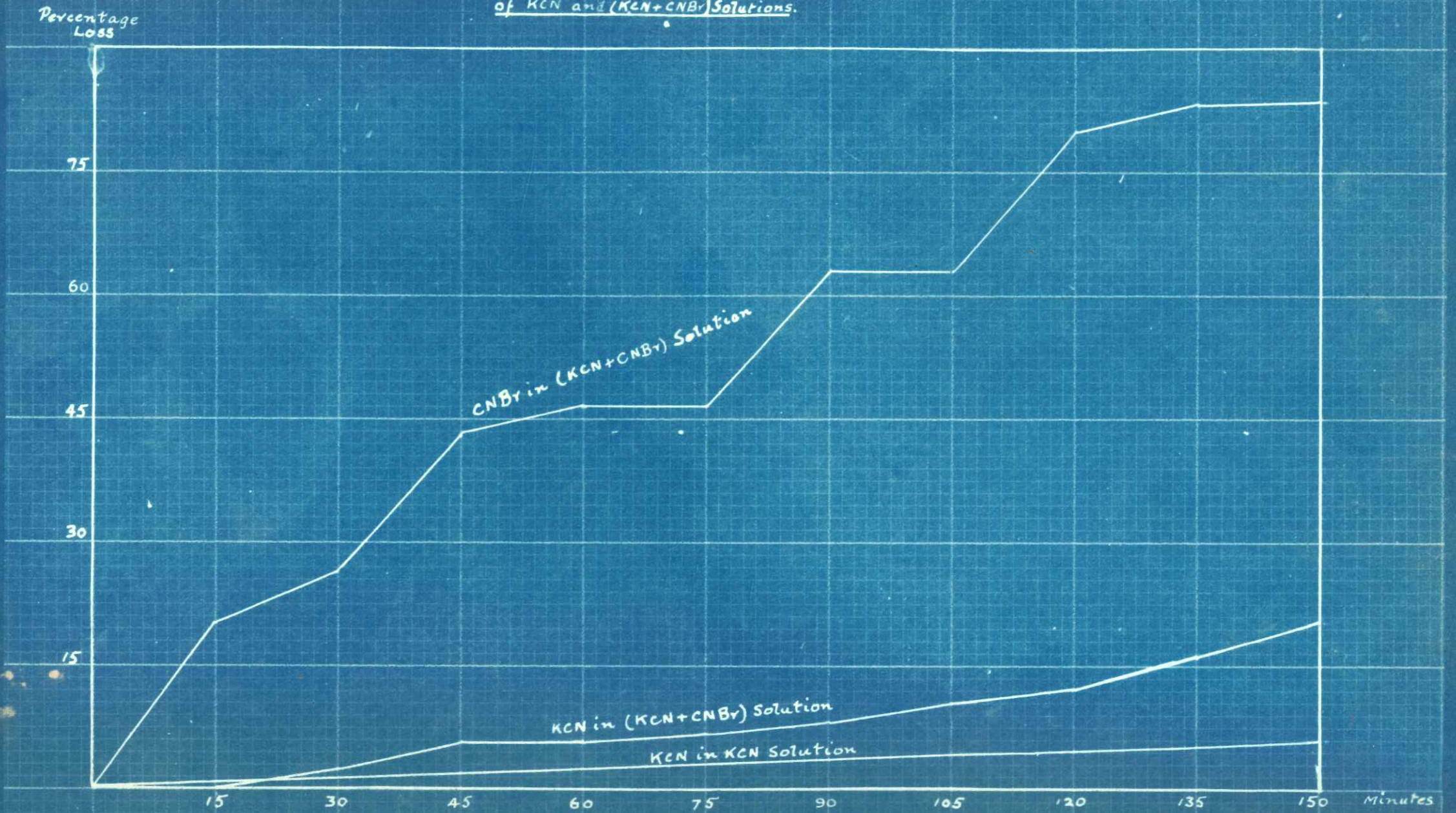
4. FLOTATION OF ORE AND BROMOCYANIDATION OF CONCENTRATE.



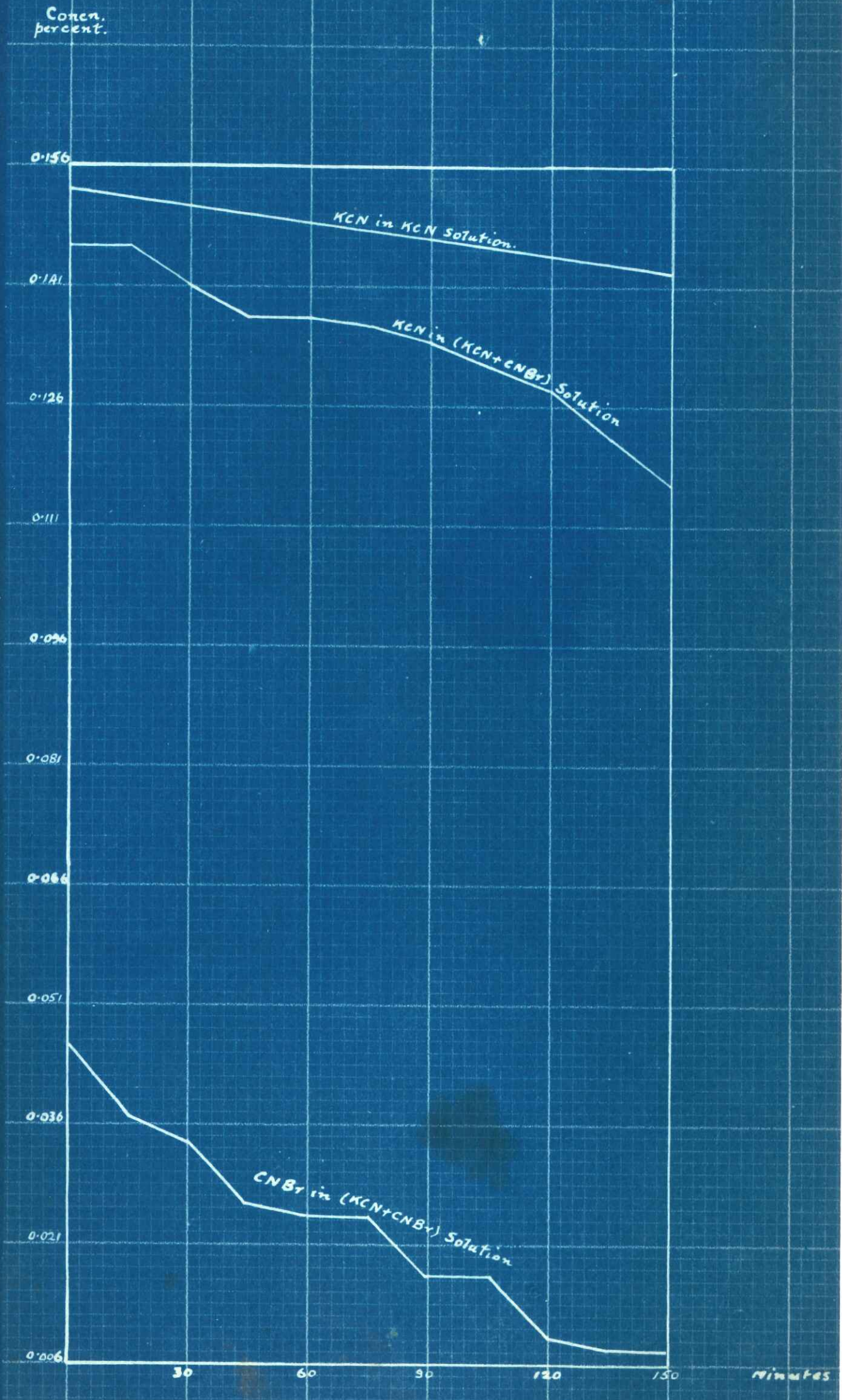
5. FLOTATION OF ORE AND ROASTING AND CYANIDATION OF CONCENTRATE.



Percentage Loss During Air Agitation
of KCN and (KCN+CNBr) Solutions.



Decrease in Concentration During Air Agitation
of KCN and (KCN+CNBr) Solutions.



DECOMPOSITION OF CYANIDE AND CYANOGEN BROMIDE BY AIR AGITATION.

Although it has been generally considered by metallurgists who have had operating experience of the bromo-cyanidation of Kalgoorlie ores that agitation of the ore pulp by means of air was inimical to the process on account of the rapid decomposition of cyanogen bromide by atmospheric oxygen, there is apparently no reference in the literature of the subject to this fact nor to the decomposition of cyanogen bromide under these conditions.

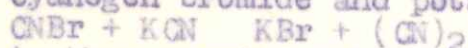
The following table shows the results obtained by air agitation of plain cyanide solution and mixed cyanide and cyanogen bromide solution, testing of the solutions being carried out at intervals of fifteen minutes.

		<u>KCN + CNBr Solution</u>				<u>KCN Solution</u>			
		KCN, 0.146% = 2.92 lb. per ton of soln. CNBr, 0.046% = 0.92 lb. per ton of soln.				KCN, 0.153% = 3.06 lb. per ton of soln.			
Agitn. time, min.	Concn. of solution		Percentage Loss (cumulative)		Consumption lb. per ton of solution (cumulative)		Concn. KCN, per cent.	%age Loss KCN	Consumption, lb. per ton of soln. KCN
	KCN, per cent.	CNBr, per cent.	KCN	CNBr	KCN	CNBr			
0	0.146	0.0460	-	-	-	-	0.153	-	-
15	0.146	0.0369	0.00	19.78	0.00	0.182	0.152	0.65	0.02
30	0.142	0.0338	2.74	26.52	0.04	0.244	0.151	1.31	0.04
45	0.137	0.0261	6.16	43.26	0.18	0.398	0.150	1.96	0.06
60	0.137	0.0246	6.16	46.52	0.18	0.428	0.149	2.61	0.08
75	0.136	0.0246	6.85	46.52	0.20	0.428	0.148	3.27	0.10
90	0.134	0.0169	8.22	63.26	0.24	0.582	0.147	3.92	0.12
105	0.130	0.0169	10.96	63.26	0.32	0.582	0.146	4.57	0.14
120	0.128	0.0092	12.33	80.00	0.36	0.736	0.145	5.23	0.16
135	0.122	0.0077	16.44	83.26	0.48	0.766	0.144	5.88	0.18
150	0.116	0.0076	20.55	83.48	0.60	0.768	0.143	6.54	0.20

The above figures show that the decomposition or removal of cyanogen bromide in a mixed solution is comparatively rapid, although after one hour's agitation by means of air, over fifty per cent. of the cyanogen bromide is still present and the solution is therefore still efficient as a solvent of gold, whereas after two hours' agitation, the proportion of cyanogen bromide still remaining is so small that the dissolving action of the mixed solution will be very slight after this time. Hence, when air agitation is adopted, the maximum time of treatment after addition of cyanogen bromide is approximately two hours.

It is difficult to explain the loss of cyanogen bromide by the action of atmospheric oxygen but it is possible that the loss on air agitation is largely mechanical, i. e., the

readily volatile cyanogen bromide is carried out of the solution by the air bubbles leaving the solution, or it may be that the violent agitation due to the introduction of air hastens the reaction between cyanogen bromide and potassium cyanide



and the cyanogen is then carried out of the solution by the air.

At the same time, the loss of potassium cyanide during the air agitation is much greater in the mixed solution than in a plain cyanide solution, which is probably due, in part, to the reaction between cyanogen bromide and potassium cyanide, and in a less degree to the decomposition of potassium cyanide by the carbon dioxide introduced with the air.

BROMOCYANIDATION OF ARSENICAL ORE.

From time to time bromocyanidation tests have been carried out on Wiluna ore which contains both pyrite and mispickel, the gold being associated for the most part with the latter mineral. Although the inventors of the bromocyanidation process and the early advocates of the process claimed that this process was particularly adapted to the treatment of arsenical ores and arsenical concentrates, it has been found that bromocyanidation of Wiluna ore possesses practically no advantages over direct cyanidation, both being incapable of yielding anything approaching a commercial extraction. The following tests indicate the results obtained by this method of treatment of this ore.

BROMOCYANIDATION OF WILUNA ORE.

Treatment conditions : Pulp ratio, 1 solids : 2.33 solution
KCN solution, 0.5 per cent. KCN
CNBr added, 1 lb. per ton
Head assay, 5.2 dwt. gold per ton
Grading, 96.5 per cent. - 150 mesh.

Fest No.	289	290	291	292	293	294
Agitation (with KCN time, hrs. (with CNBr	14	18	22	22	21.5	21.5
CaO added (initially lb. per ton (finally	2	2	2	2.7	2.5	2.5
Pregnant solution, KCN per cent.	5	10	10	10	5	10
KCN consumption, lb. per ton	-	5	5	5	5	5
Method of agitation	0.3175	0.2975	0.2925	0.4475	0.3585	0.4080
Residue, dwt. Au per ton	8.15	9.04	9.26	2.34	7.075	4.6
Extraction per cent.	air	air	air	bottle	bottle	bottle
	3.6	3.55	3.7	3.6	3.2	3.2
	30.77	31.73	28.84	30.77	38.46	38.46

In tests 293 and 294 the ore was first agitated for two hours with lime water to destroy latent acidity, the pulp filtered and agitated with the cyanide solution.

It appears therefore that this ore is not amenable to treatment by bromocyanidation

SUMMARY.

This investigation has been conducted for the purpose of determining the applicability of cyanogen bromide to the cyanidation of refractory gold ores, more particularly the

sulphotelluride ores of Kalgoorlie, and of ascertaining

(a) the operating conditions essential for successful bromocyanidation, and

(b) the cause of the inability to obtain a satisfactory extraction from these ores by plain cyanidation.

The results indicate clearly that the sulphotelluride ores of Kalgoorlie are capable of yielding a high percentage extraction by treatment with cyanide and cyanogen bromide provided that a number of important conditions are carefully controlled.

The experimental work has furnished information leading to the following conclusions :-

1. Fine grinding - at least to minus 150 mesh - is imperative.
2. Amalgamation of the finely ground ore is advisable before cyanidation in order to remove at once all free gold which is too coarse to be dissolved in a short time by cyanide or cyanide and cyanogen bromide solution.
3. Agitation of the ore with cyanide and cyanogen bromide solution may be effected mechanically or by means of air, although in the latter case the decomposition of cyanogen bromide is more rapid than in the former but not so rapid as seriously to impair the accelerating action of the cyanogen bromide on the solvent action of cyanide in the short period after addition of cyanogen bromide during which agitation is necessary in order to dissolve the gold contained in the telluride minerals.
4. In the treatment of ore the minimum effective proportion of cyanogen bromide is one pound per ton of ore. Larger additions of cyanogen bromide are not advisable on account of the great increase in cost, except in the case of the treatment of high grade concentrate or telluride minerals where it is essential that the concentration of cyanogen bromide be maintained until the maximum quantity of gold is dissolved.
5. For the treatment of ore the best concentration of cyanide solution appears to be 0.15 per cent. free potassium cyanide, i.e., this concentration yields the highest extraction, whereas much weaker solutions - 0.1 per cent. free KCN - or much stronger solutions - 0.2 or 0.25 per cent. free KCN - yield lower extractions.
6. During the preliminary agitation with cyanide alone the lime added to protect the cyanide from decomposition should be only just sufficient to produce protective alkalinity in the solution at the end of this period, since the solution during the bromocyanidation period should be neutral or slightly acid for maximum extraction. Although the consumption of cyanide is diminished by the use of an alkaline pulp, the extraction of gold is also diminished, because cyanogen bromide is rapidly decomposed in an alkaline solution and therefore its solvent action is not fully made use of, whereas, owing to its greater stability in neutral or acid solution, full advantage is taken of its solvent action when the pulp shows no protective alkalinity. Even if the solution after preliminary treatment with cyanide solution shows slight protective alkalinity, addition of cyanogen bromide solution which is always acid, may neutralise the alkalinity and yield a satisfactorily acid solution for the bromocyanidation. If the solution after the preliminary cyanide treatment period shows high protective alkalinity owing to the necessity of using considerable quantities of lime during this treatment to protect the cyanide from decomposition and so bring about a low cyanide consumption, it is advisable at the beginning of the

- bromocyanidation period to add sufficient sulphuric acid to make the pulp either neutral or slightly acid.
7. The time of agitation with cyanide alone will depend on the rate of solution of the easily extractable gold, but in all probability, not more than three hours' agitation is necessary in ordinary cases.
 8. The consumption of cyanide that takes place during the bromocyanidation period is comparatively small, most of the consumption taking place during the preliminary treatment with cyanide alone.
 9. During the bromocyanidation period the extraction of the gold is rapid while the concentration of cyanogen bromide is high. For this reason no advantage is gained by continuing the agitation after the cyanogen bromide has all been decomposed, the time of which varies from one to two hours according to the quantity of cyanogen bromide originally added. Agitation with cyanogen bromide should, however, be continued until decomposition of cyanogen bromide is complete, usually one hour for an addition of one pound of cyanogen bromide per ton of ore.
 10. No advantage is gained by adding cyanogen bromide at intervals during the bromocyanidation period.
 11. After completion of the bromocyanidation period, lime should be added to the pulp to regenerate free cyanide, i.e., calcium cyanide from the hydrocyanic acid produced during this stage. The free hydrocyanic acid is completely converted into calcium cyanide within half an hour after addition of lime, after which time decomposition of the calcium cyanide commences, while, if agitation is continued for more than one hour after addition of lime, re-precipitation of gold takes place. Consequently, after addition of lime, agitation should not be prolonged and the ore charge should be filtered not longer than one hour after addition of lime.
 12. The gold in the Kalgoorlie ores is present in at least two distinct forms, viz., that associated with the pyrite and that in combination with tellurium in the tellurides.
 13. The gold in the pyrite is amenable to cyanidation with cyanide alone and does not necessitate the employment of cyanogen bromide as an accelerator.
 14. The gold in combination in the tellurides can not be extracted by plain cyanide solution but dissolves readily and rapidly in a mixed cyanide and cyanogen bromide solution.
 15. The telluride minerals may be concentrated, without at the same time concentrating the pyrite, by flotation without or with a depressant and without or with a frothing agent. When no frothing agent is used the tendency of the calcite in the ore to produce a froth is made use of for forming the froth necessary to collect the tellurides. The use of a depressant of pyrite is unnecessary since this mineral shows but little tendency to float unless a conditioning agent, such as potassium xanthate, is used to assist its flotation.
 16. Under properly controlled treatment conditions, using cyanide and cyanogen bromide, it is possible in short periods of treatment to extract over ninety per cent. of the total gold in the ore, but in order to do so it is necessary to exercise strict control over the alkalinity of the treatment solution.

Note. The term "conditioning agent" is used to include substances such as the xanthates which react chemically with the sulphides, forming water-repellent films of base metal xanthates and therefore bring the mineral particles into a condition in which they are readily floated

For determination of alkalinity, see Appendix.

SELENIDES IN KALGOORLIE ORES.

Although the presence of selenide of silver has been noted by Dr. Simpson, very little information is available regarding the percentage of selenium in any of the ores. In the determination of tellurium in a flotation concentrate produced without addition of flotation reagents and in a sample of rich telluride ore it was found that the following percentages of selenium and tellurium were present in the two samples :-

	<u>Concentrate</u>	<u>Telluride Ore.</u>
Selenium, per cent.	0.15	2.6
Tellurium, per cent.	0.31	14.6

Both elements were determined by precipitation with sulphur dioxide, selenium being precipitated as red elemental selenium in strongly acid solution from which tellurium is not precipitated, while the latter was precipitated as black elemental tellurium after removal of the selenium and dilution of the filtrate.

The only analyses showing percentages of selenium in these telluride minerals that appear to have been published are due to Wobling (*Über einige Tellurgoldsilberverbindungen von den Westaustralischen Goldgangen*, P. Krusch, 1901-*Centralblatt für Mineralogie*) which are quoted by J. Allan Thomson in a paper on the "Tellurides of Kalgoorlie" published in the *W. A. Chamber of Mines Journal*, September 30th, 1912. Three analyses showing selenium are given, as follows :-

Petzite, $(AgAu)_2Te$ - Selenium, 1.45 per cent.; Tellurium, 32.60 per cent.

Sylvanite, $AuAgTe_2$ - Selenium, 0.20 per cent; Tellurium, 60.83 per cent.

Calaverite, $AuTe_2$ - Selenium, 1.13 per cent; Tellurium, 58.63 per cent.

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TREATMENT OF OXIDISED COPPER

ORES BY THE CONTACT

PROCESS,

BY

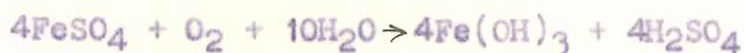
B. H. MOORE.

TREATMENT OF OXIDISED COPPER ORES BY THE CONTACT PROCESS.

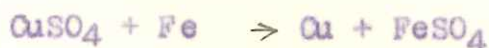
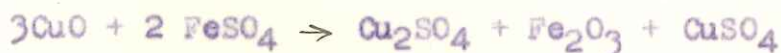
The principle of this process as set out by the inventor, P. W. Nevill, is the precipitation of metallic copper in an ore pulp by agitation of the ore at elevated temperatures in a pulp containing a small percentage of sulphuric acid, or ferrous sulphate, or ferrous chloride, together with the necessary amount of finely divided iron to precipitate the whole of the copper.

The reactions proposed to explain the action are as follows:-

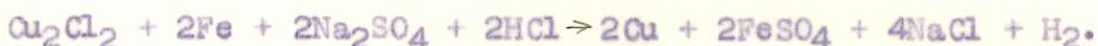
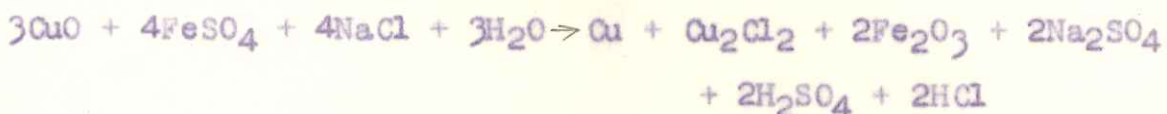
(a) Using sulphuric acid.



(b) Using ferrous sulphate.



(c) Using ferrous chloride. (in practice $\text{NaCl} + \text{FeSO}_4$)



This process was investigated in the Metallurgical Laboratory of the School of Mines in 1922 and 1923 by A. S. Winter and myself (Annual Report, Mines Dept. W. A., 1923), when it was found that the process could be successfully applied in the laboratory and that the precipitated copper could be successfully floated from the ore pulp, the recovery of copper varying from 80 to 90 per cent.

SPONGE IRON FOR PRECIPITATION.

One of the essentials of this process is the cheap production of sponge iron for copper precipitation. The company controlling the patents (Copper Separation Ltd. of Perth) spent much time and capital in endeavouring to develop a cheap method of production of sponge iron, with varying success, until the company's manager conceived the idea of introducing lump iron ore into a small producer along with the charcoal used for gas production. The first experiment in this direction was encouraging, but subsequent experiments failed to give similar results.

At this stage of the experimental work (early in 1925) I was requested by the company to proceed to their works at Kundip, Phillips River Goldfield, to assist in this investigation, and with the approval of the Mines Department I spent a month endeavouring to develop this process.

A rectangular experimental sponge iron furnace was built of steel plate in conformity with my suggestions, the furnace being

11 feet 6 inches high by 4 feet by 6 feet with a 9 inch lining of a local refractory stone. In this furnace twelve air inlets were provided on each side of the furnace, in four horizontal rows of three each, spaced 2 feet apart, the air pipes being of half an inch diameter and spaced 2 feet apart. In this way, using a light air blast and feeding ironstone broken to 3 inch ring with the charcoal, a deep zone of incandescence was obtained. The product removed from the bottom of the furnace was dropped into a water seal under the furnace to prevent oxidation of the reduced iron. The mixture of reduced iron and excess charcoal was withdrawn from the seal and after removal of the larger lumps of charcoal, the residue was ground in a wet ball mill and concentrated on a Wilfley table, the concentrate being kept under water until required for use. By this method a product containing up to 70 per cent. metallic iron was produced from a local iron ore assaying 56.7 per cent. iron, equivalent to 81 per cent. ferric oxide. Subsequent tests with the experimental furnace confirmed the early results and on my second visit later in the year the experimental furnace was used several times for the production of sponge iron for use in the treatment plant. The carbon monoxide produced in the furnace was used for steam raising in a Babcock and Wilcox boiler.

EXPERIMENTAL INVESTIGATION OF ORE TREATMENT.

In June 1925, in accordance with the request of Copper Separation Ltd, I was instructed to proceed to Kundip to assist the company's staff in an advisory capacity in carrying out large scale testing on low grade residues from the Harbour View mine and on ores from various mines in the district. On account of alterations to the plant being in progress it was impossible to proceed with large scale testing and consequently two months were spent in continuous laboratory investigation of the treatment of the low grade Harbour View residues. The object of this laboratory investigation was to endeavour to establish definite lines on which this low grade material might be economically treated, both by direct flotation of the pulp as a whole, and also by flotation after removal of the greater portion of the slime by elutriation.

At the commencement of this experimental work I found that ordinary methods of treatment and flotation would not be likely to yield good results, mainly on account of the comparatively small quantity of copper to be recovered, but also on account of the large proportion of colloidal slime present in these residues. This experimental work showed, however, that comparatively clean copper floats could be obtained by using sodium silicate as a reagent for the prevention of flotation of colloidal slime with the cement copper, the silicate being added to the pulp in the flotation machine, either during the preliminary flotation or during the re-cleaning of the preliminary float. It was found also that the use of kerosene was of considerable assistance in this direction, the kerosene acting partly as an oiler of the cement and partly as a froth stabiliser. The use of kerosene for these purposes enabled comparatively clean floats to be obtained, and also, which was of great importance, enabled a froth to be obtained which was readily controllable. For the additional purpose of further oiling and collecting the cement copper in a coherent form in a heavily loaded froth, a mixture of blackboy (Xanthorrhoea) tar and blackboy distillate, in equal proportions, was mainly used, although the results of comparative tests on the use of other oils led to the conclusion that somewhat better results could be hoped for when using other oils and mixtures of oils, such as pyridine, coal tar, and eucalyptus oil. At the same time, it was necessary to

endeavour to obtain the best results possible with blackboy tar and distillate mixture, as these were the only flotation oils in stock at the plant in sufficient quantity for full scale treatment.

During the whole of this preliminary laboratory testing attention was focussed mainly on the attainment of a satisfactory recovery of copper only, although it was recognised that the simultaneous recovery of gold values was no less important, and that on the recovery of this metal might depend the success, or failure, from an economic point of view, of this method of treatment as applied to low grade material of the nature of the Harbour View residues. Hence, the recovery and extraction of the gold was not taken into account in this preliminary work, although the results of small scale testing previously carried out by the company's staff led to the conclusion that a recovery of forty per cent., or over, of the gold values might be expected.

In considering the results of this experimental work in the laboratory, it must be borne in mind that there is a great difference in treating such low grade material as these residues and in treating freshly mined ore, for in the former case the proportion of metallic copper present in the pulp bears a very low ratio to the proportion of other solids in suspension in the pulp after the reaction necessary for precipitation of the copper, and therefore it is much more difficult to produce a high grade cement copper than in the latter case in which the ratio of copper to other solids is very much greater. In the latter case it is much easier to produce a coherent precipitate which will yield a firm froth carrying a high percentage of copper and a comparatively low percentage of slime than where the quantity of copper to be collected is small. Therefore, in considering the extractions based on the difference between the values of the head and of the residues, it must be remembered that, whereas flotation residues of a certain value might indicate a comparatively high extraction on a high or medium grade ore, yet, residues of the same value produced in the treatment of very low grade material would indicate a greatly diminished extraction on this latter class of material. For instance, residues assaying 0.5 per cent. copper would, in the treatment of 3 per cent. ore, indicate an extraction of 83.3 per cent., whereas residues of the same value from the treatment of 1.5 per cent. ore would indicate an extraction of only 66.6 per cent. There may, possibly, be a limiting value below which it is not possible, economically, to reduce the value of the residues, and therefore, equally efficient treatment of both classes of material would give percentage extractions differing very materially in the two cases, although the residues from the treatment of the two classes of material were of the same grade. Therefore, in considering the results of tests on different grade materials, either small or full scale, due regard must be paid to the relative grades of these materials before deciding whether the test work has been efficient, or the reverse. The economic aspect of this point must also be taken into account, for, although it may be possible to produce lower grade residues from low grade ores, such results may be obtained at a much enhanced cost and may therefore not be a commercial proposition. In other words, the best extraction metallurgically is not always the best extraction commercially, as the extra cost of securing the increased extraction may be greater than the value of the additional metal recovered. Hence it may very often be possible that an extraction of 66 per cent. is a better commercial proposition than one of 80 per cent. This fact must particularly be borne in mind in connection with the treatment of low grade material such as the Harbour View residues.

In all the laboratory testing carried out by me during my stay at Kundip the ore used has been Harbour View residues assaying

from 1.43 to 1.8 per cent. copper. The average value of the dump of this material, which is estimated to contain approximately twelve thousand tons, is 1.48 per cent. copper and 3.5 dwt. gold per ton, these assay values having been obtained by systematic sampling of the dump.

The company's manager appeared to have a preference for treatment of Harbour View residues by elutriation as against direct flotation, and it was therefore decided to investigate the treatment from both aspects. My own experience in the treatment by flotation of gold ores containing high percentages of colloids led me to expect that successful results might be obtained on the Harbour View residues by the adoption of similar principles, or modifications thereof, to those which I had found successful in the case of Kalgoorlie ores. I therefore decided to investigate the problem of the recovery of the copper (a) by direct flotation immediately subsequent to the reaction, and (b) by elutriation of the slime after the reaction, followed by flotation of the precipitated copper. In addition, the reaction for the precipitation of the copper was also investigated.

It was expected that the elutriation method would be open to the objection that it would be very difficult to prevent some at least of the precipitated copper from being carried away in suspension with the slime overflow from the elutriating vessel. This was found to be borne out both in the laboratory and in the plant, the result being that high extractions or recoveries could not be obtained by this method.

PRECIPITATION REACTION.

The reactions by means of which copper is precipitated in metallic form, as originally put forward, consisted of a cycle of operations involving decomposition of the copper minerals at 70°C. by the action of a solution of ferrous sulphate and sodium chloride, and simultaneous precipitation of metallic copper, by means of metallic iron, from the chlorides of copper so formed. I found at Kundip that for testing purposes it was necessary to depart somewhat from this original intention and to use sulphuric acid instead of ferrous sulphate, and sodium chloride was not available for plant work. This modification of the original process does not materially affect the efficiency of the reaction, nor is it wasteful of reagents, for the reactions by means of which the copper is precipitated are cyclic and go on simultaneously, so that the solvent action on the copper is partly due to sulphuric acid and partly to ferrous sulphate formed during precipitation of copper from copper sulphate by iron. Hence, it is not necessary to use sulphuric acid in quantity chemically equivalent to the copper present, although the minimum quantity of acid suitable for any particular ore has to be determined. This minimum quantity has been determined for Harbour View residues by experimental work in the laboratory, although it was found that somewhat higher recoveries could be obtained by the use of ferrous sulphate and sodium chloride than by the use of sulphuric acid. Since the acid used is considerably less than the amount chemically equivalent to the copper present, and since also the two reactions of decomposition of the copper minerals and precipitation of metallic copper are cyclic and go on simultaneously, it follows that a definite period of time must of necessity be allowed during which the reactions of decomposition and precipitation may proceed as nearly as possible to completion. This period has been found in the laboratory to vary from ten to twenty minutes, and a similar period has been found necessary in

full scale work. The speed of these reactions depends also on the temperature at which they are carried out and it has been found that the reactions are rapid at 70°C. and slow at lower temperatures, and that no material benefit is obtained by performing the reactions at higher temperatures; in fact, at the higher temperatures and under the vigorous agitation and aeration of the charge in the pachuca there is a strong tendency for some of the precipitated copper to become oxidised and return into solution, causing low recoveries and subsequent difficulties during flotation. Although sulphuric acid has been used in these tests, ferrous sulphate is produced in solution by the reactions, and eventually the solutions will become so charged with ferrous sulphate that the addition of only a small quantity of sulphuric acid may be necessary when treating continuously, in order to compensate for loss of ferrous sulphate by wastage and oxidation. Hence, when the plant is running on continuous treatment, the sulphuric acid necessary should be reduced to a minimum and the real solvent or decomposing agent will be ferrous sulphate acting in conjunction with the sodium chloride originally present in the mine water used for treatment purposes. Laboratory experiments have been carried out, using as decomposition agents, (a) sulphuric acid, (b) sulphuric acid and sodium chloride, (c) ferrous sulphate and sodium chloride. These experiments have shown that

1. the presence of sodium chloride assists the reactions and tends to give higher recoveries than when this salt is absent,
2. higher recoveries of copper are possible when using ferrous sulphate and sodium chloride than in either of the other cases,
3. sulphuric acid used alone gives the lowest extractions,
4. the proportion of sulphuric acid necessary varies from ten to twenty pounds per ton of residues,
5. the quantities of ferrous sulphate and sodium chloride necessary vary from ten to forty pounds and ten to twenty pounds per ton, respectively, but the circuit solution gradually becomes sufficiently charged with these salts during the reaction to render further additions either unnecessary or only necessary in small amounts; hence, in continuous treatment, the addition of salts for the decomposition of the ore becomes very small and the cost of these reagents is reduced to a minimum, because during the treatment, the necessary salts are regenerated and the only losses are due to oxidation of ferrous sulphate and loss by wastage,
6. the time necessary for the reaction varies from ten to twenty minutes,
7. the quantity of sponge iron, which depends on the grade of the ore, is slightly greater than the quantity of copper contained in the charge, varying from a ratio of iron to copper of one to one up to six to five,
8. for the treatment of Harbour View residues by direct flotation it is advisable to heat the charge to the necessary temperature of 70°C. as rapidly as possible, and to carry out the reaction and the whole of the treatment with as little delay as possible after the requisite temperature has been reached; otherwise, long continued heating of this material tends to convert the colloidal slime to a condition in which it is extremely difficult to prevent its flotation along with the copper, and, where steam is used for heating the charge, condensation of this steam over a long period reduces the density of the pulp to such an extent that flotation difficulties are increased,
9. the reactions can be efficiently carried out in a pulp containing forty to fifty per cent. of solids, and flotation

- is efficient in a pulp of the same or but very little lower density,
10. for the treatment of raw oxidised ores, long continued heating of the charge at 70°C. or over appears to have no harmful effect on flotation, except as regards dilution of pulp,
 11. agitation of the pachuca charge during treatment must be vigorous and efficient so as to bring every particle of copper mineral into contact with the reagents.

It was not found possible to investigate the applicability of the reaction to the treatment of copper sulphide ores, although the treatment of these ores should offer no difficulty, providing roasting is efficiently carried out. In fact, treatment in this case should offer less difficulty and at the same time be less expensive if the roasting of the ore is so controlled as to oxidise completely the copper sulphides, and at the same time to produce from the sulphides of iron the ferrous sulphate necessary for the reaction. It may even be possible to control the roasting operation so that the greater portion of the copper sulphides shall be converted to copper sulphate or basic sulphates of copper, which would require a minimum of decomposition reagents during the reaction in the precipitation of the copper.

The results of the laboratory testing indicate therefore that the reaction can be carried out efficiently and economically on ores and low grade cupriferous residues with the reagents mentioned, but variations in the class of ore treated will render it imperative that the conditions of treatment for each type of ore must first be investigated and laid down by systematic laboratory testing.

A few miles from the company's plant there is a large deposit of jarosite, a sulphate of iron and potassium, which I considered might possibly be utilised in connection with this process, either for the production of the necessary sulphuric acid or sulphate of iron or for assisting the reaction without preliminary treatment of the mineral. To obtain some information on this matter, I carried out a short laboratory investigation on the effect of the use of raw and roasted jarosite on the reaction. The results were interesting and encouraging and indicated that further experimental work in this direction might be warranted, for, in the laboratory tests on the treatment of Harbour View residues with this material, both raw and roasted, and without the use of acid, extractions ranging from forty to fifty four per cent. of the copper were obtained. These tests were not, owing to lack of time, carried sufficiently far to determine the applicability of this mineral, but the results indicate that it may be possible to make use of this mineral in the process, with a consequent reduction of cost due to decrease in the amount of acid and other reagents used.

FLOTATION.

One essential point in the flotation of cement copper is the necessity of carrying out the flotation as soon as possible after the precipitation of the copper, for the finely divided and spongy nature of the precipitate renders it very liable to oxidation, at least superficially, on account of the extremely large surface exposed, especially under the conditions of agitation by means of air in the treatment pachuca and in air lifts used for elevating the pulp. This liability to oxidation is not materially diminished, even after ciling of the charge, although the particles of copper are then filmed with oil. In this oxidised or superficially oxidised condition, the copper particles become coated with a film

of oxide which effectually prevents flotation unless special methods are adopted for the removal of the oxide film. For the same reason, flotation of the cement copper is greatly assisted by the introduction into the flotation machines of reducing gases, such as producer gas, instead of air, which minimise the oxidation of the copper.

Although all flotation tests in the plant were carried out with blackboy tar and blackboy distillate as flotation reagents, this does not indicate that this mixture is the most efficient flotation reagent for cement copper, for comparative laboratory tests showed that somewhat better recoveries could be made when using mixtures of eucalyptus oil, coal tar, and pyridine. In flotation tests on Kalgoorlie ores we discovered that the use of kerosene in conjunction with heavier oils assisted flotation of the sulphides by producing a quiet, controllable froth, very free from colloidal matter. Anticipating that similar beneficial results might be obtained by its use in connection with the flotation of cement copper, particularly in the case of material containing considerable proportions of colloidal slime, such as the Harbour View residues, I decided to carry out flotation of the copper on similar lines to those adopted for the flotation of auriferous sulphides, viz., using kerosene as an oiler and froth stabiliser, and a mixture of blackboy tar and blackboy distillate in equal proportions as a frother and collector. My anticipations in this direction were fully realised and I was thus enabled to produce, in the presence of the colloidal slime, a quiet, controllable, and well loaded froth, which gave no trouble in the flotation machines.

In addition to the use of kerosene for the production of a steady, controllable froth, it became necessary to adopt some method of preventing, in part at least, the flotation of colloidal slime along with the copper, so that a comparatively high grade cement might be produced. This result was obtained by the use of sodium silicate, which was added to the flotation machines in quantities varying from two to four pounds per ton of ore. This resulted in a clean float, which, in some laboratory tests, assayed as high as eighty per cent. copper.

In all direct flotation tests in the plant, the necessary oils - kerosene and blackboy tar and distillate - were added in the requisite quantities to the hot charge in the pachuca immediately after completion of the reaction. The oiling of the precipitated copper was thus carried out under the most favourable conditions, for the tar mixture is very liquid at 70°C. and is therefore readily emulsified by the vigorous agitation produced by the action of the air lift. These oils were added to the charge, kerosene first, and then the blackboy mixture, in the necessary weighed quantity, the whole of the oil being added at once, and not at intervals. Under these conditions oiling was efficient. In the case of elutriation tests, however, it was impossible, from the nature of this method of treatment, to add the oils in the same way, for this method involves, after treatment, the separation of sand and cement copper from slime before flotation. For this reason it was necessary to perform the oiling operation after the elutriation operation, and for this purpose a small pachuca was placed in position between the elutriation tank and the flotation machines. The underflow from the elutriation tank was kept in agitation in this pachuca by an air lift and was kept hot by a steam jet. The oil was introduced by means of a mechanical oiling device into this pachuca immediately above the discharge opening, which was placed about two feet below the top of the pachuca. This arrangement naturally did not tend to give the most efficient oiling,

for some of the added oil must have been discharged directly without being emulsified and brought into contact with the precipitated copper. This weakness, however, is not accountable solely for the failure to obtain satisfactory recoveries by the elutriation method, although it no doubt had some influence on the results. The main cause of non-success with this method of treatment lay in the inherent defects of the process which are particularised in the results of the elutriation tests.

RECOVERY OF CEMENT COPPER.

The product from the cleaner float flotation machine, after thickening, gravitated to an agitator from which it was to be pumped into a small Johnson filter press. This press was found to be quite unsuitable for this purpose and therefore the cement produced in each test was filtered by gravity through xanvas, dried, weighed and assayed. This procedure was adopted because it was found impossible to rely on the ^{copper content} of the flotation residues for determination of the percentage extraction and because it was considered more satisfactory to determine the extraction of copper from the amount of copper actually recovered. This recovery is shown in conjunction with the extraction calculated from the value of the head and the residues.

PLANT TESTS.

The flotation machines installed in the plant were not sufficient in number to enable results to be obtained in concordance with those obtained in the laboratory, where flotation could be continued until the charge was clean. In spite of all disadvantages, results were obtained in the treatment of both Harbour View residues and of mine ore which, under the circumstances, were considered to be highly satisfactory. In the early stages of this work, facilities were not available for filtering the cement copper and the results of the tests had to be calculated from the residue ^{content} values. In the following description of these tests, "extraction" is calculated on the difference between the copper ^{content} values of the head and residue samples, while "recovery" is based on the actual weight of copper recovered. The latter is of greater value than the former, as it indicates the commercial result of the test, since the crucial test of the process is the percentage of copper actually recovered. The comparatively crude method of recovering the cement copper, however, entailed unavoidable losses which tended to make the recovery lower than the extraction.

TESTS ON RAW ORE - DIRECT FLOTATION.

	Test 1	Test 2	Test 3
Head Value, per cent. Cu	3.0	4.04	4.04
Ore charge, tons	7.5	2.5	2.5
Per cent. solids in pulp	-	43.0	42.1
Sulphuric acid used, lb. per ton	25	24	24
Iron used, lb.	500	230	230
Ratio iron : copper	10 : 9	8 : 7	8 : 7
Kerosene, lb. per ton	0.66	0.5	nil
Blackboy mixture, lb. per ton	1.33	1.0	2.0
Reaction time, minutes	20	20	20
Sodium silicate used, lb. per ton	2	2	3
Rougher float, per cent. Cu	16.45	20.7	14.1
Cleaner float, per cent. Cu	58.75	-	-
Residue, per cent. Cu	0.87	1.24	1.27
Extraction, per cent.	71.0	69.3	68.5
Recovery, per cent.	-	59.4	58.2
Flotation time, hours	5	1.2	1.4

The ore for Test 1 was raw ore while that for tests 2 and 3 was a mixture of raw ore and Harbour View residues. In Tests 2 and 3 the cleaner flotation machine was out of commission and therefore the rougher float was passed directly to the concentrate thickener,

TESTS ON HARBOUR VIEW RESIDUES (direct flotation of copper)

Test No.	4	5	6	7	8	9	10
Head value, per cent. Cu	1.48	2.08	2.08	2.12	2.12	2.12	2.12
Ore charge, tons	5	5	2.5	2.5	2.5	2.5	2.5
Per cent. solids in pulp	42	42	42	44.5	44.5	44.5	44.5
H ₂ SO ₄ used lb. per ton	20	20	10	18	18	18	18
Iron used lb.	225	250	104	120	120	120	120
Ratio iron : copper	3:2	5:3	1:1	10:9	10:9	10:9	10:9
Kerosene, lb. per ton	0.5	0.5	0.4	0.5	0.5	0.5	1.0
BB mixture, lb. per ton	1.0	1.5	1.0	1.0	1.0	1.0	1.0
Reaction time, minutes	10	10	10	20	20	30	25
Sodium silicate, lb. per ton	n.d.	2.8	4	2	2	3	2
Rougher float, per cent. Cu	41.36	21.62	22.56	15.98	18.8	9.58	16.92
Cleaner float, per cent. Cu	53.5	52.17	39.95	48.41	64.4	33.37	39.01
Residue, per cent. Cu	0.82	0.82	0.94	1.02	1.08	1.15	1.22
Extraction per cent.	44.6	60.58	54.8	51.9	49.0	45.4	44.3
Recovery per cent.	-	-	-	-	-	46.3	57.9
Flotation time, hours	2.5	-	2	1.08	1.4	1.6	1.16

TESTS ON HARBOUR VIEW RESIDUES (elutriation)

Test No.	11	12	13	14	15
Head value, per cent. Cu	44	42	43	44	45
Ore charge, tons	2.12	2.12	2.12	2.12	2.12
Per cent. solids in pulp	2.5	2.5	2.5	2.5	2.5
H ₂ SO ₄ used, lb. per ton	44.5	43.8	43.8	43.8	43.8
Iron used, lb.	20	20	20	20	20
Ratio, iron : copper	140	110	110	110	140
Ratio, iron : copper	4:3	1:1	1:1	1:1	4:3
Kerosene, lb. per ton	}	Not determined			
BB mixture, lb. per ton					
Reaction time, minutes	25	25	25	25	25
Sodium silicate, lb. per ton	6	4.5	4.5	4.5	6
Rougher float, per cent. Cu	24.92		21.62		36.6
Cleaner float, per cent. Cu	39.01		-		-
Elutriation residue, % Cu	1.52		2.11		1.69
Flotation residue, % Cu	1.10		0.89		1.03
Recovery per cent.	29.18		35.8		28.3
Flotation time, hours	1.4		5.4		1.05

Tests 12, 13, and 14 were run consecutively and the cement copper from the three tests was collected as one concentrate in the thickener.

This method of treatment of the residues can not be recommended on account of the practical impossibility of preventing precipitated copper from being carried away with the slime overflow during the process of elutriation. The high copper value of the elutriation residue shows that this is taking place, and this is confirmed by the effluent from the elutriation tank depositing finely divided cement copper as a film on the surface of the pulp in the residue thickener during the progress of elutriation.

CONCLUSIONS.

My experience with the process on a working scale, although obtained in an inefficient plant, indicates that this process is capable of making quite a satisfactory recovery of copper from raw

oxidised ores of varying grades and also from very low grade material. Such recovery can only be made in an efficient plant and slight modifications in the method of treatment may be necessary for different types of ore..

26th October, 1925.

APPENDIX.

ANALYTICAL METHODS.

CYANIDE SOLUTIONS.

Free Cyanide.

To 50 c.c. of solution add 5 c.c. of 1 per cent. potassium iodide solution and titrate with standard silver nitrate solution until solution is permanently cloudy.

The standard solution of silver nitrate is made up so that when 50 c.c. of cyanide solution are taken for assay, each c.c. of silver nitrate solution is equivalent to 0.01 per cent. KCN, i.e., by dissolving 6.519 gram pure AgNO_3 in distilled water and diluting with distilled water to 1000 c.c.

Protective Alkali.

To the solution after determination of free cyanide add silver nitrate in excess, add 1 drop of 1 per cent. alcoholic phenolphthalein solution and titrate with standard oxalic acid solution until the pink colour is destroyed.

The standard solution of oxalic acid is made by dissolving 14.25 gram pure crystallised oxalic acid in water and diluting to 1000 c.c. On a 50 c.c. sample of cyanide solution, each c.c. of oxalic acid solution is equivalent to 0.01 per cent. CaO .

Gold.

To 5 Assay Tons (1 A.T. = 29.166 c.c.) of solution add 10 c.c. of a 10 per cent. lead acetate solution, then 2 gram zinc shavings. Heat below boiling point for about 25 minutes. Add 20 c.c. concentrated hydrochloric acid and continue heating until effervescence ceases. Press the spongy lead into a cake, decant off solution and wash the lead. Press the lead into a compact mass, place in a piece of lead foil with sufficient pure silver for parting, leaving an opening for escape of steam, cupel, and part with dilute nitric acid.

Cyanogen Bromide.

To 50 c.c. of cyanide solution add just sufficient acetic acid to make the solution acid, add 2 gram potassium iodide, shake well and allow to stand five minutes. Titrate with standard sodium thiosulphate solution, using starch indicator. (The end point is quite sharp without the use of the indicator.)

If the solution to be tested is acid, make slightly alkaline with sodium carbonate and then just acid with acetic acid before addition of potassium iodide.

The sodium thiosulphate solution (0.1N) is standardised by titration against a standard solution of potassium dichromate whose iron equivalent has been accurately determined. Dilute 20 c.c. of dichromate solution to 100 c.c., add 5 c.c. concentrated hydrochloric acid and 2 gram potassium iodide. Shake well and allow to stand five minutes. Titrate with thiosulphate solution, using starch indicator.
 CNBr equivalent of dichromate = Fe equivalent \times 0.9464.

ORE ANALYSIS.Sulphur.

To 0.5 gram of ore add 10 - 20 c.c. of a saturated solution of potassium chlorate in concentrated nitric acid. Allow to stand in a warm place for 10 minutes, then evaporate slowly to dryness on the hot plate. Add 2 gram pure sodium carbonate and 100 c.c. of boiling water. Boil ten minutes, filter and wash well. Make filtrate slightly acid with hydrochloric acid and boil till all carbon dioxide is expelled. Add from a pipette, drop by drop, 10 c.c. of a boiling 10 per cent. solution of barium chloride, with constant stirring. Allow to stand on hot plate until barium sulphate settles out completely. Filter and wash with boiling water until filtrate is free from chlorides. Incinerate filter paper and ignite residue and weigh as barium sulphate.

Weight $BaSO_4 \times 0.1373 =$ Weight Sulphur in sample taken.

Selenium and Tellurium.

Weigh 10 gram of ore into a 400 c.c. beaker. Add 25 c.c. water, 2 gram potassium chlorate and 15 c.c. nitric acid. Digest for 30 minutes in the cold and then evaporate to dryness on a steam bath. Cool and add 15 c.c. HCl. When violent action ceases, evaporate to dryness on the steam bath. Add 150 c.c. water and 15 c.c. HCl and warm on the steam bath until all soluble salts are dissolved. Filter and wash four or five times with hot water. Heat the clear filtrate to boiling, remove from the hot plate and add HCl equal to one-fourth the volume of the solution. Pass into the solution a stream of SO_2 . Red selenium is first precipitated and on continued passing of SO_2 black tellurium is precipitated. Continue passing SO_2 until the precipitate coagulates. Wash down the delivery tube and filter. Wash two or three times with cold water. Place paper and precipitate in original beaker, add 10 c.c. concentrated HNO_3 , and break up filter paper with a glass rod. Heat on steam bath until precipitate is completely dissolved. Dilute to 25 c.c., filter off the paper pulp and wash well with several small portions of water. Evaporate filtrate to dryness on the steam bath. Add 10 c.c. concentrated HCl and 2 gram NaCl; heat to boiling and boil gently for one minute. Saturate with SO_2 while hot. Red selenium is precipitated from the concentrated acid, free from tellurium. Pour on to a weighed Gooch crucible, decanting the suspended selenium from the residue of undissolved NaCl. Wash three times with HCl (9 acid : 1 water) and then add water to the beaker to dissolve the remaining NaCl. Pour the solution through the Gooch crucible and then wash with water till all NaCl has been dissolved. Dry on steam bath, cool in a desiccator and weigh as Se.

Dilute filtrate from the Se to 300 c.c., heat to boiling and again pass SO_2 until well saturated. Black Te is completely precipitated in HCl of 25 to 60 per cent. concentration. Filter on a weighed Gooch crucible and wash with dilute HCl (1:3), followed by five washes with water. Dry on the steam bath, cool in the desiccator and weigh as Te.

Copper.

Decompose 0.5 gram ore with concentrated HNO_3 and HCl. Evaporate to small bulk, cool, add 7 c.c. concentrated H_2SO_4 , and heat until copious fumes of SO_3 are evolved. Cool, dilute to 100 c.c., add 10 c.c. bromine water and boil till all bromine is expelled. Add NH_4OH until a faint permanent precipitate forms. Add 10 c.c. glacial acetic acid, cool, add 3 gram ammonium fluoride, stir until dissolved, and add 3 gram KI. Shake well, allow to stand five minutes, and titrate with standard sodium thiosulphate solution, using starch indicator.

Lime, CaO, in Commercially lime.

Weigh 2 gram of sample into a litre flask and fill to the mark with a sugar solution containing 20 gram sugar per litre. Stopper flask and shake at intervals for an hour. Allow to stand over night. Shake well and take out 250 c.c. and titrate with normal hydrochloric acid, using phenolphthalein as indicator.