# Studies on Nundydroog gold ore with a view to improving gold recovery

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SYNOPSIS

*Extensive laboratory studies were undertaken in the National Metallurgical Laboratory on samples collected from Kolar Gold mill to determine the cause of gold losses in the cyanidation tailings and to develop a suitable method to improve the gold recovery. The studies indicated (i) gold in the run-of-mine ore was mostly present as native form, a part of which was found to be finely disseminated in arsenopyrite and quartz. No tellurides were detected in the sample and the presence of minor amounts of graphitic carbon was not responsible for gold losses in the tailings ; (ii) cyanidation studies undertaken on the feed to the cyanidation plant, indicated that an increased agitation time of 27 hours reduced substantially gold losses in the residue and recovered 94.6% of the total gold, (iii) presence of minute grains of gold associated with arsenopyrite was mainly responsible for the gold losses in the residue. Recovery of arsenopyrite by tabling or flotation after wet magnetic separation produced concentrates assaying 4·8 to 5·2 dwt Au per ton with an additional recovery of 3·3% gold. The final table or flotation rejects assayed 0·1 to 0·14 dwt Au per ton representing a total loss of 1·6 to 2·2% gold only in the final tailing.*

*Results of the cyanidation studies undertaken on the current tailing sample which have been cyanided for only 12 hours are also included in the paper. Studies have clearly indicated that 50% of the gold lost in it could be recovered by subjecting the same to cyanidation for another 15 hours. Recovery of a heavy mineral concentrate by tabling produced a concentrate assaying 3·6 dwt. Au/ton and represented an additional gold recovery of 3·8% Au with respect to run-of-mine ore. The results confirm the earlier findings that arsenopyrite carried bulk of the gold lost in the final cyanidation residue.*

GOLD is distributed widely in India though occurrence in workable quantities are not many. The most important gold mines are found in Kolar Gold Field situated in Mysore State. Although some 26 quartz lodes more or less parallel are known to occur, only one reef namely, the Champion, is being exploited and all the four mines viz., Mysore, Champion, Oregaum and Nundydroog have been developed along its strike. During the last few years the ore from the western reef of Nundydroog is being mined in large tonnages. Nearly 21 000 tons per month are milled and the ore as an average carried a gold content of 5·6 dwt/ton. Since the ore body is highly mineralised, several metallurgical problems, such as greater wear and tear of machineries, difficulties during cyanidation due to the presence of sulphides, increased consumption of chemicals and higher tailing values are experienced at Kolar.

At the instance of Ministry of Finance, Government of India, detailed discussions were held at Nundydroog between Officer-in-Charge (Ore Dressing), National Metallurgical Laboratory and the Chief Metallurgist, Kolar Gold Fields, about the gold extraction problems at Kolar. During the discussions, it was pointed out by the latter that the gold loss in the final cyanide residue was gradually increasing during the past few years as per the tailing assays given in Table I. Consequently, detailed laboratory investigations were undertaken at Nundydroog to determine the causes for the declining gold recovery and to improve the plant efficiency. One of the principal causes attributed to the increasing gold losses, as a result of their studies, was the presence of graphite which caused premature precipitation of gold during cyanidation. Presence of tellurides in the sample was also suspected as this also results in increased gold losses in the tailing. It was agreed that, keeping these observations in view, National Metallurgical Laboratory should undertake detailed studies on their problems and suggest suitable modifications to the existing plant to improve the gold recovery, which at present was only about 90%.

As desired by NML, three samples namely (1) run-of-mine ore after tertiary crushing, (2) feed to cyanidation plant and (3) final cyanidation tailing were received from Nundydroog for studies. The results obtained from each of these samples are presented in this paper.

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**TABLE I Final residue assay**

| Year | dwt/gold/ton | % Au loss |
|---|---|---|
| 1959/60 | 0·308 | 55% |
| 1960/61 | 0·300 | 5·4 |
| 1961/62 | 0·293 | 5·2 |
| 1962/63 | 0·270 | 4·8 |
| 1963/64 | 0·271 | 4·8 |
| 1964/65 | 0·490 | 8·8 |
| 1965/66 | 0·469 | 8·4 |

## Sample No. 1 : run-of-mine ore

One of the problems confronted at Kolar is the frequent change in the characteristics of the ore body and its highly mineralised nature. Hence the ore was subjected to detailed mineralogical studies in National Metallurgical Laboratory to determine the form in which gold is present and the nature of its association with the various gangue minerals.

The ore was hard and compact and was composed of sulphides and siliceous minerals. The colour of the siliceous minerals varied from colourless to white dark grey. The non-metallic minerals identified in thin sections as well as in grain mounts of representative sieve fractions consisted of hornblende, chlorite, biotite and quartz. Chlorite and biotite were seen as alteration products of hornblende.

The metallic minerals identified under ore microscope in the order of abundance were pyrrhotite, (5·7% by volume), arsenopyrite (2·2% by volume) chalcopyrite (0·1% by wt.) and magnetite with traces of marcasite and pyrite. Gold was detected in the siliceous gangue where it was present as comparatively coarse veins and particles of 4 to 20 microns in dimensions. It was also found to be finely disseminated in arsenopyrite usually less than 4 microns in size. Traces of graphite were present in the finer sieve fractions. The liberation of sulphides from siliceous gangue was observed at 200 mesh size.

Microscopic studies could not detect the presence of tellurides in the sample. Spectrographic analysis also indicated the absence of tellurium in the sample. These findings ruled out the possibility of tellurides being responsible for the gold losses in the residue. The presence of finely disseminated gold particles in arsenopyrite and traces of graphite in the finer sieve fractions was kept in view when the cyanidation studies were undertaken on the feed to the cyanidation plant.

## Sample No. 2 : feed to the cyanidation plant

The sample which was received in sealed drums had 8–9% moisture in it and was mostly in the form of fines. Part of it was air dried and used for experimental work. Sieve analysis indicated that it contained 66·8% −200 mesh. The chemical and spectrographic analysis are recorded in Table II.

**TABLE II Chemical and spectrographic analysis**

| Constituent | % |
|---|---|
| Total S | 2·9 |
| Au | 2·3 dwt/ton |
| Fe | 13·3 |
| $Al_2O_3$ | 7·6 |
| $SiO_2$ | 55·5 |
| CaO | 7·8 |
| MgO | 4 3 |
| As | 0·41 |
| Pb, Zn, Cu (spectrographic analysis) ... | trace |
| Te (spectrographic analysis) ... | absent |

The gold content in run-of-mine ore and feed to the cyanidation sample was found to be 5·6 and 2·3 dwt/ton respectively. Thus, the gold recovered at Kolar by blanket strake must have been 3·3 dwt/ton Au equivalent to a recovery of 59·0% Au from the run-of-mine ore. It is reported that the average gold recovery during previous years, by blanket strake was about 70%, but the present studies show that the recovery is much lower viz., 59%. The present feed to cyanidation plant has a gold distribution of 41·0% in it.

### *Experimental results*

Representative samples were subjected without further grinding to cyanidation tests for different lengths of time, to determine the optimum time of agitation, for maximum recovery of Au. The tests were carried out by the bottle agitation method, keeping the solid liquid ratio at 1 : 2·5. The NaCN and CaO concentrations were maintained at 0·018 and 0·008% respectively throughout the tests by requisite additions of NaCN and lime, whenever necessary, determining their strength during agitation. The residues obtained after cyanidation were fire assayed. The time of agitation, the quantities of NaCN and lime actually consumed, the extraction percentage of Au, etc. are recorded in Table III.

The overall gold recovery with respect to run-of-mine ore which stood at 59·0% before the commencement of cyanidation increased gradually with increase in cyanidation time reaching 87·5% after 12 hours and

**TABLE III Cyanidation results of sample no. 2**

| Time of agitation in hours | Reagents consumed NaCN kg/ton | CaO kg/ton | Au left in residue dwt/ton | Gold extraction % with respect to Cyanidation feed | Run-of-mine ore |
|---|---|---|---|---|---|
| 0 | — | — | 2·3 | — | 59·0 |
| 3 | 0·16 | 0·5 | 1·4 | 39·0 | 75·0 |
| 4 | 0·18 | 0·55 | 1·2 | 47·8 | 78·6 |
| 6 | 0·20 | 0·6 | 1·0 | 56·5 | 82·1 |
| 8 | 0·21 | 0·675 | 0·9 | 60·9 | 83·9 |
| 10 | 0·225 | 0·7 | 0·8 | 65·2 | 85·7 |
| 12 | 0·25 | 0·75 | 0·7 | 69·5 | 87·5 |
| 24 | 0·26 | 0·8 | 0·5 | 78·2 | 91·1 |
| 27 | 0·27 | 0·85 | 0·3 | 87·0 | 94·6 |
| 32 | 0·275 | 0·9 | 0·3 | 87·0 | 94·6 |
| 48 | 0·28 | 0·95 | 0·3 | 87 0 | 94·6 |

the higher value of 94·6% after 27 hours, beyond which no further increase was observed even at the end of 48 hours. The actual NaCN and lime consumption at the end of 27 hours agitation were 0·27 and 0·85 kg/ton respectively.

The present practice at Nundydroog is to cyanide the feed to the mill for only 12 hours. Evidently due to incomplete cyanidation, the Au content in the residue carried as high as 0·5 to 0·6 dwt/ton of Au and represented an overall loss of 9 to 10·7% Au. The results obtained at National Metallurgical Laboratory clearly showed that by increasing the cyanidation time to 27 hours, the gold loss in the residue could be brought down to 5·4% Au.

## *Flotation of graphite*

Mineralogical studies on the sample had indicated the presence of minor amounts of graphite in the 150 and 200 mesh sieve fractions. In order to ascertain whether the presence of graphite caused premature precipitation of gold and increased the gold losses in the cyanidation residue, the sample was subjected to froth flotation for graphite removal. The graphite was floated using pine oil.

The float contained only minor amounts of graphite but assayed 4·8 dwt/ton Au. The graphite-free flotation tailing was cyanided as before for 27 hours keeping the cyanide and lime concentrations at 0·018 and 0·008% respectively. The cyanide residue upon analysis was found to have a gold content of 0·3 dwt/ton. This indicated that removal of graphitic carbon prior to cyanidation did not reduce that gold losses in the residue, which remained the same, irrespective of whether the cyanidation feed contained graphite or not.

Since the cyanide residue still contained 0·3 dwt Au/ton and accounted for an overall gold loss of 5·4%, studies were made next to determine the nature of the gold present in it and recover the same if possible by suitable methods.

## *Separation of sulphide minerals*

Since pyrrhotite and arsenopyrite constituted the chief sulphide minerals, the distribution of Au in these sulphides was studied. Wet magnetic separation was employed for separation of pyrrhotite from cyanide residue using a continuous wet magnetic separator. The magnetic fraction, which was mainly pyrrhotite, was kept aside while the non-magnetic fraction was subjected to flotation for recovery of arsenopyrite. The conditions for arsenopyrite flotation are recorded in Table IV.

**TABLE IV Conditions for arsenopyrite flotation**

| Reagent added | Qty. kg/ton | Cond. time mts. | Flotn. time mts. | Product |
|---|---|---|---|---|
| Soda ash | 1·0 | — | — | — |
| $CuSO_4$ | 0·5 | — | — | — |
| Aerofloat 25 | 0·03 | 12 | 5 | Float |
| Amyl xanthate | 0·08 | — | — | — |
| Pine oil | 0 04 | — | — | — |
| (pH at the end – 9·2) | | | | |

The rougher arsenopyrite float was cleaned once and a refloat concentrate and a refloat tailing were collected. The assay results of the various products are recorded in Table V.

**TABLE V Wet magnetic separation and flotation**

| Product | Wt.% | Assay Au dwt/ton | Dist.% Au w.r.t. flotation feed | Dist.% Au w.r.t. feed to cyanidation plant | Dist.% w.r.t. r.o.m. ore i.e., 5·6 dwt/ton Au |
|---|---|---|---|---|---|
| Magnetic | 3·9 | 0·3 | 3·5 | 0·5 | 0·2 |
| Refloat conc. 1 (arsenopyrite conc.) | 3·8 | 4·8 | 55·0 | 8·0 | 3·3 |
| Refloat tailing | 3·2 | 0·4 | 3·9 | 0·6 | 0·2 |
| Prim. tailing | 89·1 | 0·14 | 37·6 | 5·4 | 2·2 |
| Head (calc.) | 100·0 | 0·33 | 100·0 | 14·5 | 5·9 |

The results recorded in Table V showed that the Au content in the magnetic fraction was practically the same as in the feed, but the refloat concentrate (arsenopyrite float) was high in gold content viz., 4·8 dwt/ton. Examination of the refloat concentrate under microscope revealed that arsenopyrite constituted the bulk with minor amounts of chalcopyrite. No free grains of gold were present but minute grains of gold associated with arsenopyrite were noticed. Since arsenopyrite is refractory to cyanide treatment, the same was left uncyanided and lost in the cyanidation residue, thereby increasing the gold losses. Recovery of arsenopyrite fraction by flotation would give an additional recovery of 3·3% gold, thus raising the overall gold recovery from 94·6 to 97·9%.

*Tabling of the cyanidation residue*

A test was next performed in which tabling was done alternatively for recovery of arsenopyrite from the residue. The residue left after cyanidation was subjected to wet magnetic separation as before and the non-magnetic fraction was passed over a laboratory shaking table. Three products viz., a concentrate, middling and a tailing were collected. The assay results of the various products are recorded in Table VI.

**TABLE VI Wet magnetic separation followed by tabling**

| Product | Wt.% | Assay Au dwt/ton | Dist.% Au w.r.t. cyanidation residue | Dist.% w.r.t. cyanidation feed | Dist.% w.r.t. r.o.m. ore |
|---|---|---|---|---|---|
| Mag. conc. | 3·9 | 0·3 } 2·65 | 3·6 | 0·5 | 0·2 |
| Table conc. | 3·6 | 5·2 } | 58·8 | 8·1 | 3·3 |
| Middling | 3·4 | 0·9 | 9·9 | 1·3 | 0·5 |
| Table tailing | 44·1 | 0·1 | 13·6 | 1·9 | 0·8 |
| Slimes | 45·0 | 0·1 | 14·1 | 1·9 | 0·8 |
| Head (calc.) | 100·0 | 0·318 | 100·0 | 13·7 | 5·6 |

The table concentrate assayed 5·2 dwt/ton and represented a distribution of 58·8% Au with respect to table feed. This product, when recovered, would represent an additional recovery of 3·3% Au with respect to run-of-mine ore. If the process of wet magnetic separation is eliminated, the pyrrhotite fraction would also report in the table concentrate, in which case, the table concentrate would assay 2·65 dwt gold/ton with a recovery in this product of 3·5% gold. The tabling results also thus confirmed the earlier findings that arsenopyrite fraction alone carried a substantial portion of the gold lost in the final cyanidation residue at Nundydroog. Recovery of arsenopyrite fraction by flotation or tabling will finally reject a cyanidation residue assaying 0·1 to 0·14 dwt/ton of Au only.

**Sample No. 3 cyanidation residue sample from Nundydroog**

The sample no. 3 received in National Metallurgical Laboratory was a cyanidation residue obtained after 12 hours cyanidation at Nundydroog. It assayed 0·54 dwt. Au/ton, 3·1% S, 13·6% Fe, 6·8% $Al_2O_3$, 56·1% $SiO_2$. 0·4% As, with traces of Pb, Zn, and Cu, and represented a gold loss of 9·6% in it. The objective in undertaking studies on this sample was to confirm some of the earlier findings that were already established with sample No. 2 and also to recover the gold lost in it by suitable methods.

Studies on the feed sample to the cyanidation plant (sample no. 2) had clearly shown that it should be cyanided for 27 hours to obtain maximum recovery of Au, when the cyanidation residue would assay only 0·3 dwt Au/ton. Since the present sample assaying 0·54 dwt/ton is a cyanide residue obtained after 12 hours of agitation only at Nundydroog, it was felt that by increasing the duration of cyanidation, it should be possible to obtain higher Au recovery. Hence further cyanidation studies were performed with representative samples for different lengths of time keeping the NaCN and lime concentration at 0·018 and 0·005% as before. The results are recorded in Table VII.

**TABLE VII Cyanidation results (sample no. 3)**

| Cyanidation time | Au in the residue dwt/ton | %Au recovered with respect to feed | %Au recovered with respect to run-of-mine ore (assaying grade of 5·6 dwt/ton) |
|---|---|---|---|
| 15 hrs | 0·27 | 50·00 | 95·20 |
| 24 hrs | 0·26 | 51·90 | 95·40 |
| 48 hrs | 0·26 | 51·90 | 95·40 |

The results showed that improved overall gold recoveries at Kolar could be achieved up to 95·4% by simply increasing the cyanidation time to 27 hours. The residue obtained after 15 hours' agitation (or a total of 27 hours including the 12 hours at Nundydroog) had a gold value of 0·26 dwt/ ton only.

**Tabling of the cyanidation tailing**

Earlier studieson the cyanidation residue, obtained from the sample of feed to the cyanidation plant, showed that the gold recoveries could be substantially improved by recovering the arsenopyrite fraction which contained finely disseminated gold. Recovery of arsenopyrite by tabling was hence attempted from the tailing sample (sample no. 3) also. The 12 hours cyanided sample was passed over a laboratory shaking table and a concentrate, tailing and slime were collected. The assay and distribution of gold in the various fraction are recorded in Table VIII.

**TABLE VIII Results of tabling (sample no. 3)**

| Product | Wt.% | Assay Au dwt/ton | Dist.% Au dwt/ton w r.t. feed | Dist.% Au dwt/ton w.r.t. run-of-mine ore |
|---|---|---|---|---|
| Table conc. | 5·9 | 3·6 | 47·4 | 3·8 |
| Table tailing | 45·0 | 0·35 | 35·1 | — |
| Table slime | 49·1 | 0·16 | 17·5 | — |
| Head (calc.) | 100·0 | 0·45 | 100·0 | — |

The results indicated that a heavy mineral concentrate assaying 3·6 dwt/ton and representing a gold recovery of 3·8% Au with respect to run-of-mine ore could be recovered from the cyanidation residue. Microscopic studies of the heavy mineral concentrate confirmed that arsenopyrite carried bulk of the gold and its recovery by tabling method would improve the overall gold recovery to 94·3%

**Summary**

Studies on three samples of gold from the Nundydroog mines, viz. (1) run-of-mine, (2) feed to the cyanidation plant and (3) final cyanidation tailing before it is sent to cyclones, were undertaken in National Metallurgical Laboratory, at the instance of the Ministry of Finance, Government of India, to determine the causes for the declining gold recovery at Nundydroog and suggest suitable methods for improving the plant efficiency.

The run-of-mine ore (sample no. 1) assaying 5·6 dwt Au/ton was subjected to detailed mineralogical examination so as to determine the nature of association of gold with various gangue minerals. Pyrrhotite, arsenopyrite and chalcopyrite constituted the chief sulphide minerals with minor amounts of marcasite and pyrite. Gold was present as native gold associated with siliceous gangue and arsenopyrite. The liberation of sulphides from siliceous gangue was observed at about 200 mesh size. No tellurides were found to be present with the sample.

*Sample No. 2*

The sample of feed to the cyanidation plant (sample no. 2) assaying 2·3 dwt/ton Au and representing 41·0% of the gold in the run-of-mine ore was subjected to cyanidation studies using 0·018% NaCN and 0·008% lime for different lengths of time in a bottle agitator. It was observed that an agitation time of 27 hours was the optimum which would recover 87% of the gold in the cyanidation feed corresponding to a recovery of 94·6% with respect to run-of-mine ore. This compares with the present day gold recovery at Nundydroog of only 90% where the practice is to cyanide the ore only for 12 hours. The NaCN and lime consumptions, at the end of 27 hours cyanidation, were found to be 0·27 and 0·85 kg/ton respectively.

As graphite present in the sample was reported to cause premature precipitation of gold, the ore was subjected to flotation using pine oil as collector for graphite. The flotation residue still assayed 0·3 dwt Au/ton, thereby indicating that the presence of minor amounts of graphite in the sample was not the cause for the gold losses in the cyanide residue.

Efforts were next directed towards recovery of gold from the residue obtained after 27 hours' cyanidation. Wet magnetic separation, followed by xanthate flotation of the non-magnetic fraction, produced arsenopyrite concentrate analysing 4·8 dwt/ton gold and representing 55% gold distribution with respect to flotation feed and equivalent to an additional 3·3% Au recovery with respect to run-of-mine ore.

Equally satisfactory results were obtained when tabling was adopted alternatively for arsenopyrite recovery. Wet magnetic separation of the cyanidation residue, followed by tabling of the non-magnetic fraction, yielded an arsenopyrite concentrate assaying 5·2 dwt/ton Au with a recovery of 58·8% Au with respect to table feed. The recovery of Au in this product with respect to feed to the cyanidation plant was of the order of 8·1% equivalent to 3·3% with respect to run-of-mine ore. The final cyanidation tailing assayed only about 0·1 dwt/ton of gold. Thus improved gold recoveries of over 98% could be achieved by increasing the cyanidation time to 27 hours and subjecting the cyanidation residue to tabling or flotation for arsenopyrite recovery. Gold recovery from arsenopyrite is usually accomplished by roasting and cyanidation.

*Sample No. 3*

Attempts were next made to recover gold lost in the present day cyanidation tailings (obtained after 12 hours' cyanidation) of Nundydroog mine, Kolar (sample no. 3). The sample assayed 0·54 dwt/ton of gold representing a gold loss in this product of 9·7% with respect to run-of-mine ore.

Further cyanidation studies made on the sample indicated that nearly 50% of the gold present in it could be recovered if it was subjected to an extra 15 hours' cyanidation. The final cyanidation residue assayed 0·26 dwt/ton Au and the loss of gold in this product with respect to the run-of-mine ore would be only 4·8% Au. These findings confirm that a total of 27 hours' cyanidation time is required to effect an overall gold recovery of 95%.

Straight tabling with the 12 hours cyanided sample produced a heavy mineral concentrate assaying 3·6 dwt/ton Au, with distribution of 47·4% gold with respect to table feed and equivalent to an additional

recovery of 3·8% Au with respect to run-of-mine ore giving an overall recovery of 94·3% Au. Evidently cyanidation for 27 hours is to be preferred. Since the gold present in the fraction is interlocked with arsenopyrite, the same should be roasted and then cyanided. An arsenopyrite concentrate could be produced by flotation also.

### Conclusion

The run-of-mine ore (sample no. 1) assayed 5·6 dwt Au/ton whereas the feed to cyanidation plant assayed 2·3 dwt/ton, showing that 3·3 dwt/ton had been recovered at Nundydroog during the blanket straking representing a recovery of 59% Au. The feed to the cyanidation plant at Nundydroog carried 41% of the total gold in it.

87% of the gold present in the feed (sample no. 2) to the cyanidation plant at Nundydroog or 35·6% with respect to run-of-mine ore could be extracted by subjecting the ore to cyanidation for 27 hours effecting an overall gold recovery of nearly 95%. This compares with the reported overall gold recovery at Nundydroog of only 90%, where cyanidation is done only for 12 hours. It is thus clear that by just increasing the cyanidation time by another 15 hours, an extra 5% gold recovery can be obtained.

To obtain still higher recoveries of gold, the cyanidation residue after 27 hours cyanidation will have to be subjected to flotation or tabling when an arsenopyrite concentrate having a gold value of 4·8 to 5·2 dwt/ton and representing an additional recovery of 3·3% Au with respect to run-of-mine ore could be recovered. The final loss of gold in cyanidation residue after flotation or gravity treatments would be of the order of 1·6 to 2·2% when the values are calculated on the basis of run-of-mine ore. Thus there should be no difficulty in getting an overall recovery of 98%, by producing an arsenopyrite concentrate by flotation or tabling from the cyanide residue and recovering the gold therefrom by roasting and cyanidation.

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