CHAPTER 3
AMENABILITY STUDIES OF COMPLEX SULPHIDE ORES FROM VARIOUS MINES IN INDIA
3.1 INTRODUCTION

Bacterial leaching technology implies as the first step the amenability of ore to bacterial attack. Amenability study of an ore is conditioned by its mineralogical and chemical composition. Mineralogical composition provides information on the different minerals present. The base-metals, iron sulphides, carbonates and clay minerals as well as their intergrowths are of major importance [54]. Carbonates and other alkaline gangue contents provide information regarding sulphuric acid consumption during the complete process [23, 99, 213]. Once the base-metal sulphide contents are known, the maximum amount of metal values recoverable by bacterial leaching can be estimated. Knowledge of sulphur and sulphide content of the mineral body allows prediction of metal values that can be recovered by the biologically generated sulphuric acid due to biooxidation of sulphur and sulphide moiety [50]. The presence of different sulphide elements may notify leaching kinetics of the desired metal and affect its solubility due to the galvanic interactions taking place within the ores [70, 76, 155, 200, 205]. Minerals from different sites have varied mineralogical and chemical composition resulting in variable nature of pH, acid consumption and assessibility to the bacterial culture used for bioleaching [76, 200]. These variations are due to various physico-chemical and microbial interactions taking place within the earth's crust [12, 16].

The most convenient way of assessing the amenability of a sulphide ore to bioleaching, once its chemical and mineralogical composition is known are some preliminary evaluation tests undertaken to study the pH, acid consumption, acid producing potential, survival of the bacteria used for the study and bioextraction of metals from the ores. The evaluation tests are simple, inexpensive and provide reliable data of the ore and its amenability to bioleaching [166].

Hence the above mentioned preliminary evaluation studies were carried out to determine the amenability of various complex sulphidic minerals (collected from various mines in India), to bacterial leaching.
3.2 MATERIALS AND METHODS

3.2.1 Mineral Samples

Complex sulphidic minerals from the following mines in India were collected for the study. The location of the mines is shown in the maps - 1, 2 & 3.

1. Agnigundal Mines - Andhra Pradesh
2. Ambamata Multimetal Mines - Gujarat
3. Rajpura-Dariba Mines - Rajasthan
4. Zawar Mines - Rajasthan

Mine at Ambamata multimetal project is of open-cast type while rest of the above mentioned mines are mainly underground mines. The origin of deposits of the minerals available at all the above mentioned mines is mainly of hydrothermal deposits. Ore samples, both large and fine particles were collected from different mines and brought to the laboratory for study. The ore-sample from Ambamata mine was ball-milled at the mining site itself while rest of the samples were ball-milled in the laboratory of L. D. Engineering College, Ahmedabad. Finely ground particles were separated by sieves (B.S.S) of different mesh size as per the experimental need.

3.2.2 Chemical analysis of the ore

The ore samples were acid digested followed by analysis of copper, lead, zinc and other elements present by AAS Varian 175 and standard methods of analysis [298].

3.2.3 pH of the ore

A slurry of equal parts of 44 μm (-325 mesh) particle size of the ore and distilled water (pH 7.0) was made. From the slurry a series of dilutions were
prepared in distilled water. The pH of each dilution was measured using Systronics 324 pH meter. A graph was plotted for the observed data with relation to the pH vs dilution. A straight line was obtained and the pH of the ores were determined by extrapolation of the graph [215].

3.2.4 Acid consumption of the ore

Many ores contain alkaline gangue materials which react with the sulphuric acid produced due to biological oxidation of the sulphides or added externally. Ore samples may not be amenable to leaching until sulphuric acid is added externally, in case the acid demand is not met by the biologically produced acid [215,216].

For this study, 10 gm of the ore(<44 µm particle size) was placed in a 500 ml Erlenmeyer flask containing 100 ml of distilled water (pH 7.0). Adjustment of pH was done by addition of 10% H₂SO₄ with a pipette until the sample showed a steady pH 2.5 for about one hour.

3.2.5 Acid production potential of the ore

To determine the acid production potential of the ore samples, the samples were taken in flasks as mentioned above and procedure described [214] was followed. Pretreatment was given to the samples by external addition of sulphuric acid to adjust the pH to 2.5. Once the pH was stabilised, 10 ml of actively growing culture of *T. ferrooxidans* was inoculated into the flasks, incubation was done on Newtronics Orbital shaker with 125 rpm at 30 ± 1 °C. Decrease in pH was observed due to sulphuric acid produced by biooxidation of sulphides / sulphur. A fresh sample was added at this point and pH changes were closely monitored. If pH rose and approached initial pH of the ore, the sample was confirmed to be a non acid producer, as the acid is consumed by the alkaline gangue. But if the pH remained low, the sample was confirmed as acid producer.
The biologically produced acid was titrated using standard NaOH and the values determined were then compared with the theoretical amount of sulphuric acid which could be produced, calculated stochiometrically from the total sulphur content of the ore. If alkaline content of the ore, consumed more acid than could be theoretically produced, the sample was classified as non-acid producer, but if the opposite was true, the sample could be classified as acid producer.

3.2.6 Microbial Analysis

About 10 gm of the ore samples, 44 µm, particle size were dissolved in sterile distilled water, mixed properly by keeping on shaker for a few minutes and then observed under microscope for presence of microorganisms.

3.2.7 Survival of microorganisms inoculated in the ore

10 gm of the ore samples 44 µm size were taken in two Erlenmeyer flasks containing 100 ml of 9K medium (ferrous free) [58a]. Ore sample in one flask was given pretreatment with acid. Flasks were incubated after inoculation with T. ferrooxidans. Chemical and microscopic analysis were carried out to determine the bacterial growth and its activity.

3.2.8 Organisms

Actively growing cultures of *Thiobacillus ferrooxidans* (10% v/v) were used for the experimental studies.

3.2.9 Bioleaching experiments

Once the primary evaluation tests and other chemical and microbial analysis were over the complex sulphide ore samples were subjected to bacterial attack. Bioleaching studies using shake flask techniques were carried out in duplicates with 44 um particle size and 10% pulp density of the ore samples.
in 500 ml Erlenmeyer flasks containing 100 ml of ferrous free 9K medium. Control flasks were run in parallel, added with 2% thymol in 5 ml methanol [100]. pH was stabilised by acid treatment before adding inoculum. Water loss due to evaporation was compensated using sterile-acidic distilled water [167].

3.2.10 Metal analysis

Zinc and ferrous were analysed titrometrically by EDTA and potassium dichromate methods respectively. Copper was estimated spectrophotometrically (Toshniwal - VIS Spectrophotometer), while lead was analysed by Ammonium molybdate method using tannic acid as external indicator. All analysis were done by standard methods described [298].

3.3 RESULTS AND DISCUSSIONS

Complex sulphide ores from the Agnigundal mines in Guntur, Andhra Pradesh are in the form of parallel and enechelon veins and the metals are mostly confined to the dolomites in this belt. In Gujarat, the Ambamata multimetal mines with 8.7 million tonnes reserves of copper-lead-zinc is found associated with pyrite, talc, quartz and clay materials. The Rajpura-Dariba mines with metal reserves of 40 million tonnes located in Bhilwara district and the Zawar mines near Udaipur, Rajasthan where the metals are associated with rocks like quartzites, dolomites, slates and phyllites of the Aravali system [37]. Mineralization is largely confined to the dolomite horizon. Most of the mineral deposits of the copper-lead-zinc are of hydrothermal origin [37].

Micrographs of the polished surface of the complex sulphide ore are shown in Figures 3.1 and 3.1 (a - h). The complex sulphide minerals as mined from the earth is shown in Figure 3.1. Metallic yellow or yellowish brown appearance in the ore particles is due to presence of chalcopyrite.
Figure 3.1 Complex or Polymetallic Ore Sample

Figure 3.1 (a)

Figure 3.1 (b)

Figure 3.1 (c)

Figure 3.1 (d)
Figures 3.1 (a - h) shows occurrence of combinations of mineral sulphides viz: pyrite - chalcopyrite - sphalerite - galena in the complex sulphide ores. Figure 3.1 (a) shows a combination of chalcopyrite (yellowish brown portion) with sphalerite (gray portion) while Figure 3.1 (b) depicts interaction of chalcopyrite + sphalerite and interlock galena (black portion) within the sphalerite.

Similar occurrence are observed in Figure 3.1 (d) while Figure 3.1 (c) shows interaction of pyrite (white portion) with sphalerite and chalcopyrite. Figure 3.1 (e) shows combination of a binary metal (pyrite + sphalerite). The combination of the mineral sulphides and their distributions are depicted in Figures 3.1 (f,g,h). Figure 3.1 (f) shows occurrence of chalcopyrite + sphalerite and sphalerite alone while Figure 3.1 (g) illustrates combinations of pyrite + chalcopyrite + sphalerite or chalcopyrite interlocked in pyrite. Figure 3.1 (h) shows the presence of sphalerite + chalcopyrite with occurrence of galena (black portion) within chalcopyrite and chalcopyrite alone (yellowish brown).

This is how the metal sulphides occurs in the complex sulphide ores and such occurrence of combinations or finely intergrown metal sulphides explains the difficulty of profitable mining and beneficiation / flotation of individual metals by the conventional ore processing methods.

The chemical analysis of the complex sulphide ore samples collected from various mining sites in India is depicted in Table - 3.1. Analysis show presence of varied percentage of copper, lead and zinc alongwith silver, cadmium and magnesium. There was a marginal difference (1 to 2%) in the concentration of ferrous and sulphur respectively. They differed widely in the amount of different
### TABLE - 3.1 METAL ANALYSIS OF COMPLEX SULPHIDIC MINERALS

<table>
<thead>
<tr>
<th>COMPLEX SULPHIDIC MINERALS</th>
<th>COPPER Cu</th>
<th>LEAD Pb</th>
<th>ZINC Zn</th>
<th>FERROUS Fe</th>
<th>MAGNESIUM Mg</th>
<th>SULPHUR S</th>
<th>SILVER Ag</th>
<th>CADMIUM Cd</th>
<th>PPM</th>
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<tbody>
<tr>
<td>A. AMBAMATA</td>
<td>0.80</td>
<td>3.99</td>
<td>5.35</td>
<td>4.92</td>
<td>4.99</td>
<td>8.88</td>
<td>40</td>
<td>170.00</td>
<td></td>
</tr>
<tr>
<td>B. AGNIGUNDAL</td>
<td>0.03</td>
<td>12.68</td>
<td>0.48</td>
<td>4.39</td>
<td>6.16</td>
<td>7.18</td>
<td>10</td>
<td>75.00</td>
<td></td>
</tr>
<tr>
<td>C. BAJPURA-DARIBA</td>
<td>0.17</td>
<td>2.94</td>
<td>4.90</td>
<td>5.10</td>
<td>1.12</td>
<td>8.71</td>
<td>160</td>
<td>470.00</td>
<td></td>
</tr>
<tr>
<td>D. ZAWAR TAILING</td>
<td>0.02</td>
<td>3.39</td>
<td>2.92</td>
<td>4.31</td>
<td>6.40</td>
<td>6.80</td>
<td>25</td>
<td>175.00</td>
<td></td>
</tr>
<tr>
<td>E. ZAWAR ORE</td>
<td>0.04</td>
<td>4.02</td>
<td>3.18</td>
<td>4.03</td>
<td>6.77</td>
<td>6.80</td>
<td>30</td>
<td>165.00</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE - 3.2 ACID PRODUCTION AND CONSUMPTION (g H2SO4) / 100 g ORE

<table>
<thead>
<tr>
<th>COMPLEX SULPHIDIC MINERALS</th>
<th>STOCHIOMETRIC ACID PRODUCTION [g]</th>
<th>BIOLOGICAL ACID PRODUCTION [g]</th>
<th>ACID CONSUMPTION [g]</th>
<th>pH AT THE END OF BIOLOGICAL OXIDATION</th>
<th>% SULPHUR (TOTAL) IN ORE BIOLOGICALLY OXIDISED</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. AMBAMATA</td>
<td>27.02</td>
<td>14.81</td>
<td>14.99</td>
<td>1.9 - 2.0</td>
<td>54.61</td>
</tr>
<tr>
<td>B. AGNIGUNDAL</td>
<td>22.00</td>
<td>17.98</td>
<td>52.03</td>
<td>1.5</td>
<td>81.72</td>
</tr>
<tr>
<td>C. BAJPURA-DARIBA</td>
<td>26.69</td>
<td>12.26</td>
<td>14.81</td>
<td>2.1 - 2.2</td>
<td>45.93</td>
</tr>
<tr>
<td>D. ZAWAR TAILING</td>
<td>20.83</td>
<td>15.94</td>
<td>46.93</td>
<td>1.7 - 1.8</td>
<td>76.52</td>
</tr>
<tr>
<td>E. ZAWAR ORE</td>
<td>20.83</td>
<td>16.96</td>
<td>64.80</td>
<td>1.5 - 1.6</td>
<td>81.42</td>
</tr>
</tbody>
</table>
pH of Different Complex Sulphide Ores

![Graph showing pH levels of different ores](image1)

Figure 3.2

Initial pH of the Complex Sulphide Ores from Different Mines

![Bar chart showing initial pH values of ores](image2)

Figure 3.3
metals present. A maximum of 0.8% and 5.35% of copper and zinc in the samples from Ambamata multimetal mines while a maximum of 12.68% lead in the Agnigundal mines were determined. The ore samples from Zawar mines (ore and tailings) showed 3-4% of Pb, 2-3% of Zn but very small quantity of Cu (0.02 to 0.04%). The Agnigundal ore having a maximum Pb content (12.58%) was found to contain only 0.03% Cu and 0.48% Zn.

The pH of different complex sulphide ores was determined by extrapolating the graphs and the results are shown in Figure 3.2 pH values of all the ore samples were found to be in the range of 7.5 - 8.1 (Figure, 3.3). Reports regarding the acid consumption and acid production (stochiometric and biological) is detailed in Table - 3.2. The amount of acid (concentrated sulphuric acid in grams) required to neutralise the acid consuming alkaline gangue impurities ranged between 14.81 to 64.80 g of H₂SO₄. Complex ore samples from the Ambamata and Rajpura-Dariba mines required minimum amount of sulphuric acid (14.81 and 14.99 g / 100 g ore - compared to the highest by Zawar ore (64.80 g / 100 g ore).

The varied concentrations of sulphuric acid consumed explain the difference in nature and quantity of the acid-consuming alkaline gangue impurities present in the ore samples.

The acid-production potentials of the complex ore samples were calculated both stochiometrically and biologically for production of sulphuric acid from sulphur content of the ores. Stochiometrically estimated sulphuric acid which could be produced was found to be between 20.83 to 27.02 g H₂SO₄ / 100 g ore, for different ores. Biological production of sulphuric acid by oxidation of sulphur was studied as follows : initial pH of the ore samples was adjusted to 2.5 and the final pH attained in different samples is shown in Table - 3.2. Final pH in the Agnigundal ore sample was 1.5 i.e biologically 81.72% of the total sulphur in the ore was available for bacterial oxidation, which resulted in better production of sulphuric acid, thereby reducing the pH to 1.5. Similarly 81.42
and 76.52% of sulphur in the ore samples from Zawar mines while only 45 to 54% of sulphur in the ore samples from Rajpura-Dariba and Ambamata multimetal mines was available for biooxidation to sulphuric acid, hence the pH was lowered to only 2.0 - 2.2 in these samples.

It can be explained from Table - 3.2 that though 75 to 81% of sulphur was available for biooxidation to sulphuric acid in the complex ore samples from Agnigundal and Zawar Mines, they required 46 to 64 g H₂SO₄ to be externally added to neutralise the alkaline gangue content which explains the presence of high amount of gangue impurities and also that the biologically produced acid was not enough to neutralise the same. The acidic pH shown for the different samples was the result of easy availability of sulphur to the microorganisms. Ore samples from Ambamata multimetal and Rajpura-Dariba mines required less (14.99 and 14.81g) H₂SO₄ to be externally added. This explains that the biologically produced acid was sufficient to neutralise the alkaline impurities present.

On the basis of the above data, ore samples from Agnigundal and Zawar mines can be categorised as non-acid producers while ore samples from the Ambamata multimetal and Rajpura-Dariba mines may be categorised as acid producers. The reason being availability of more than 75% sulphur for biooxidation to sulphuric acid in case of ore from Agnigundal and Zawar mines which is utilised by the gangue materials while in case of samples from the Ambamata multimetal and Rajpura-Dariba mines still about 50% of sulphur remains impregnated in the ore-bodies and may be available, with increase in incubation time for biological oxidation.

Microscopic observations of the ore samples revealed presence of several motile and non-motile cells. Association of microorganisms with the ore particles could be a good sign for amenability of the ores to bioleaching or bacterial attack. Association of indigenous flora plays a significant role in bioleaching due to their acquaintance with the prevailing ecology. Externally added bacterial cells were found to survive, though, at a different rate. Initially
Biooxidation Pattern of Ferrous/Ferric (800 h)

Figure 3.4
added inoculum contained \(10^8\) cells / ml of \(T.\ \text{ferrooxidans}\) in all the flasks containing different complex ore samples. When observed microscopically and counted after a week, the number of cells in the flasks containing ore samples from the Agnigundal and Zawar mines was found to decrease from \(10^8\) to \(10^7\) cells / ml, while the flasks containing ore samples from the Ambamata and Rajpura-Dariba mines showed an increase in the cell numbers \((10^8 - 10^9\) cells / ml). This could be explained due to wide fluctuations of pH and high alkaline gangue in the samples from Agnigundal and Zawar mines compared to less pH fluctuations and low gangue impurities in the samples from Ambamata and Rajpura-Dariba mines. Increase in cell numbers with time indicates survival as well as propagation of the cells and existing conditions favouring growth of \(T.\ \text{ferrooxidans}\).

Metabolic status of the organisms was revealed from the continuous increase in mV and ferric / ferrous ratio. This increase is also quantitatively co-related with the growth of the organisms. Figure 3.4 exhibits ferrous-ferric concentrations of the different ore samples as in inoculated and uninoculated flasks.

After the preliminary evaluation tests, studies were undertaken to determine the bioleaching of the complex sulphide ores. pH variations (Figure 3.5a-e) were observed over a period of 10 days. The initial phase saw wider and frequent pH fluctuations which consumed high amount of sulphuric acid because the acid was utilized for neutralising the alkaline gangue materials and also for chemical leaching of loosely bound metal sulphides in the ore samples [192,227]. After addition of inoculum less sulphuric acid was required, there were comparatively less pH fluctuations and pH adjustment was required only at the interval of three days where it showed an upward trend. This indicates that the amount of acid generated by the organisms was not sufficient to neutralise the gangue materials still remaining.

Due to bacterial activity, surface erosion of the particles expose new sites as well as new gangue and sulphur contents. Observed decline in pH during
pH Fluctuations During Bioleaching Studies

Figure 3.5 (a)

pH Fluctuations During Bioleaching Studies

Figure 3.5 (b)
pH Fluctuations During Bioleaching Studies

Inoculum Added

Figure 3.5 (c)

Inoculum Added

Figure 3.5 (d)
pH Fluctuations During Bioleaching Studies

Figure 3.5 (e)
active leaching phases indicates dominance of microbial activity compared to renewal of new surfaces requiring sulphuric acid. Here the comparative amount of acid produced and consumed results in net surplus acid, which reflects decrease in pH.

At the time of addition of inoculum, flasks showed 8-10% copper and 15-20% zinc leached out from the different complex sulphide ores, which may be due to chemical extraction of copper and zinc by the sulphuric acid added. Better extraction of zinc (nearly double) as compared to copper reflects easy solubility of zinc than copper under acidic conditions [Table - 3.3].

Initially in all the experimental sets, the rate of metal dissolution was slow, but it increased steadily at later stages. The rate of copper and zinc extraction in the test sets inoculated with *T. ferrooxidans* was more than double compared to the uninoculated control sets. Highest copper extraction - 31% from Rajpura-Dariba ore and highest zinc extraction - 81% from the Agnigundal ore was observed. Copper and zinc in different percentage were extracted from the complex ores, while the extracted lead (in the form of lead sulphate) being insoluble remained in the residue and was analysed at the end of the experiment.

The concentration of ferrous and ferric varied during the bioleaching periods (Figure 3.4). The concentration of ferrous was high in the control flasks, while the flasks containing inoculum showed fluctuations in the amount of ferrous and ferric, which may be due to bacterial activity and solubilization of pyrite in the ore samples. The ferrous / ferric ratio was found to increase and decrease throughout the bioleaching phase, the reasons may be that initially all the mineral sites were available for direct bacterial attack which liberated ferrous from pyrite, the liberated ferrous was utilized for growth by the bacteria and oxidised to ferric, which being a high oxidant helped in indirect leaching mechanism for extraction of metals and in the process got reduced to ferrous.
### Table 3.3 Results of Shake Flask Leaching of Different Complex Sulphide Ores [800 h]

<table>
<thead>
<tr>
<th>Complex Sulphidic Minerals</th>
<th>Copper Leached %</th>
<th>Zinc Leached %</th>
<th>Lead in Residue %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Test</td>
<td>Control</td>
</tr>
<tr>
<td>A. Ambamata</td>
<td>8</td>
<td>22</td>
<td>28</td>
</tr>
<tr>
<td>B. Agnipundal</td>
<td>5</td>
<td>23</td>
<td>36</td>
</tr>
<tr>
<td>C. Rajpura-Dariba</td>
<td>10</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>D. Jawar Tailing</td>
<td>6</td>
<td>15</td>
<td>29</td>
</tr>
<tr>
<td>E. Jawar Ore</td>
<td>7</td>
<td>17</td>
<td>31</td>
</tr>
</tbody>
</table>

### Table 3.4 Biooxidation of Ferrous to Ferric (g/l) by the Bacteria [800 h]

<table>
<thead>
<tr>
<th>Complex Sulphidic Minerals</th>
<th>Fe+2</th>
<th>Fe+3</th>
<th>Fe+2</th>
<th>Fe+3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Ambamata</td>
<td>4.60</td>
<td>5.50</td>
<td>0.70</td>
<td>3.85</td>
</tr>
<tr>
<td>B. Agnipundal</td>
<td>4.10</td>
<td>1.60</td>
<td>1.45</td>
<td>3.45</td>
</tr>
<tr>
<td>C. Rajpura-Dariba</td>
<td>5.00</td>
<td>0.85</td>
<td>1.40</td>
<td>4.30</td>
</tr>
<tr>
<td>D. Jawar Tailing</td>
<td>4.90</td>
<td>1.40</td>
<td>1.10</td>
<td>3.20</td>
</tr>
<tr>
<td>E. Jawar Ore</td>
<td>3.70</td>
<td>1.60</td>
<td>1.40</td>
<td>3.00</td>
</tr>
</tbody>
</table>

78
<table>
<thead>
<tr>
<th>COMPLEX SULPHIDIC MINERALS</th>
<th>TOTAL IRON</th>
<th>JAROSITE PRECIPITATION</th>
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<tbody>
<tr>
<td></td>
<td>CONTROL</td>
<td>TEST</td>
</tr>
<tr>
<td>A. AMBAMATA</td>
<td>5.10</td>
<td>4.55</td>
</tr>
<tr>
<td>B. AGNIGUNDAL</td>
<td>5.70</td>
<td>4.90</td>
</tr>
<tr>
<td>C. RAJPURA-DARIBA</td>
<td>5.85</td>
<td>5.70</td>
</tr>
<tr>
<td>D. ZAWAR TAILING</td>
<td>5.40</td>
<td>4.30</td>
</tr>
<tr>
<td>E. ZAWAR ORE</td>
<td>5.30</td>
<td>4.49</td>
</tr>
</tbody>
</table>
This cycle goes on. Concentration of ferric was found to increase at the end of the experiment suggesting bacterial activity [Table - 3.4].

Initial amount of ferrous ion was calculated and found to be 4-5 g/l for 10 g ore while an increase (3-4 g/l) in the amount of ferric was observed along with decrease (0.7-1.45 g/l) of ferrous, while concluding the experiments. Data in Table - 3.5 shows presence of total iron calculated for different ore samples in both the inoculated (test) and uninoculated (control) flasks. Precipitation of jarosite in the form of ferric hydroxide was unable to be detected and hence loss in soluble total iron in the test flask compared to the control flasks was observed. Amount of total iron precipitated / jarosite formed in the different ore samples varied, with the minimum 0.15 g/l and the maximum 1.1 g/l in the Rajpura-Dariba ore and Zawar tailings respectively. Various reasons are responsible for jarosite formation, one of them was the fluctuations in pH, which could be the reason for higher amount of jarosite formed on the sample from Zawar tailings.