On the basis of shake-flask, LSTR and PSTR study on GMDC polymetallic concentrate following conclusions are drawn:

✓ The concentrate is amenable to bioleaching process.

✓ The various indigenous isolates showed wide diversity of metal extraction from the concentrate.

✓ Even the best four cultures selected showed the metal extraction range of 35 to 48% for copper and 61 to 84% for zinc with 10% pulp density.

✓ The consortium showed better activity than pure culture due to improved coupling of ferrous and sulphur oxidation ability.

✓ Wild culture or consortium was found to be inhibited due to their sensitivity towards the soluble copper and zinc in the leachate.

✓ The copper concentration of 0.48±0.03 g.l⁻¹ was found to be inhibitory concentration for unadapted metal sensitive consortium.

✓ The adapted consortium showed active metal extraction and propagation even in the presence of 2.77 g.l⁻¹ of copper.

✓ The findings show that pre-washing of the concentrate did not prove to be remarkably beneficial, so there is no need of pre-washing of concentrate for the process to be economical.

✓ The use of tap water instead of distilled water proved to be equally efficient without any loss in metal extraction activity.

✓ Amongst the basal ingredients of 9K medium, the addition of K₂HPO₄ and (NH₄)₂SO₄ found to be necessary for better metal extraction ability.

✓ The concentration of (NH₄)₂SO₄ and K₂HPO₄ in the medium slightly influenced by the form of inoculum used in the process.

✓ KCl addition was not necessary as a nutrient for metal extraction from the concentrate.
Based on the results obtained through statistical design and analysis, the following factors were found to be significant in the order indicated.

- **Type of inoculum** - most significant
- **Inoculum x KCl** - highly significant (for copper extraction)
- **(NH₄)₂SO₄ x K₂HPO₄** - significant (for zinc)
- **(NH₄)₂SO₄ x K₂HPO₄ x KCl** - significant (for copper extraction)
- **(NH₄)₂SO₄ x KCl x inoculum** - significant (for copper extraction)

The factorial designing finding shows that copper extraction was influenced by more factors and their interactions than zinc.

The detailed study showed that 0.5 g.l⁻¹ [(NH₄)₂SO₄ and 0.125 g.l⁻¹ K₂HPO₄ were sufficient for optimum bioleaching ability from this concentrate.

The formulated M-2 medium was found to be more suitable for this particular bioleaching process.

Many of the essential basal salts ingredient are present in the polymetallic concentrate. Thus, considerable saving could be done by the use of formulated low nutrient medium.

The type of inocula used were arranged in terms of their increasing leaching ability as follows

- Normal flora < Unadapted consortium < 9K grown consortium < wet slurry < supernatant < leachate.

Carried over excess iron with inoculum proved to be detrimental for the process.

The presence of ferric in the system initiate jarosite formation.

20% (w/v) leachate as inoculum was proved to be the best inoculum for the process.
Conclusions

☑ The pulp density could be increased up to 25% (w/v) without any significant loss in total metal extraction when developed inoculum was used.

☑ The total metal content in the solution is also an important criteria in large scale leaching operations specially when the solubilized metals have to be recovered and the experiment at high pulp density proved to be helpful in this direction. It is pertinent to remember in above context that possible higher pulp density may have to be maintained to achieve higher metal extraction though the same would amount to slightly lower percent extraction.

☑ The overall bioleaching profiles are significantly influenced by the amount of the pulp used.

☑ The concentrate of mixed particle size within the range of -300+400 # was found to be more suitable as compared to more finer particles.

☑ Leaching system pH of 1.7±0.1 was found to be optimum.

☑ Copper extraction was more influenced at higher temperature of 42±2° C.

☑ Developed inoculum was successfully preserved for more than one year on the polymetallic concentrate without any considerable loss in bioleaching ability.

☑ Amongst the three designs studied, system replacement at every 24 h was found to be the optimum condition for fed batch process.

☑ Semi-continuous leaching process proved to be beneficial for metal extraction as compared to batch process.

☑ Metal extraction improved to 157.8 and 28.9 fold for copper and zinc in shake flask studies. Lead extraction also improved by 133.3%.
Both copper and zinc extraction remained competent even after 15 cycles of fed batch semi-continuous process.

Both minimum and maximum level of the ferrous in the system gradually decreased from 1st to the final flasks.

Semi-continuous process showed less acid consumption as compared to batch process.

Bioleaching activity in LSTR was adversely affected due to carryover adhesive in the vessel.

The observed wide variation in copper extraction as compared to zinc proved the difficult solubilization of copper from chalcopyrite.

In LSTR, the inocula showed the following decreasing order of suitability:

Leonate > Supernatant > Slurry > Iron grown consortium

The findings in the LSTR indicate the feasibility of the process with 25 to 30% pulp density by changing the mode of pulp addition.

Addition of the total pulp in small fractions showed more feasibility of the process.

In the reactor, 5-6 days residence time was found to be optimum for copper whereas 7-8 days for zinc extraction.

In LSTR, 50% transfer mode in 3 vessel cascade system showed more than 70% copper and more than 90% zinc extraction.

Considerable temperature rise was seen in PSTR due to bioleaching process.

Selection of temperature tolerant consortium resulted in competitive metal extraction in the temperature range of $42\pm2^\circ$ C.
Conclusions

✓ The overall percent metal extraction in PSTR in semi-continuous process remained around 80% for copper and 71% for zinc.

✓ The overall leaching profile range in PSTR in terms of pH, redox potential, soluble ferrous concentration, cell count were 1.96 to 2.12, 350 to 385 mV, 2.09 to 2.49 g.l⁻¹ and 2.0 to 4.4 x 10⁷ cells.ml⁻¹ respectively.

✓ The acid consumption was 4.4 g acid.Kg⁻¹ concentrate in PSTR process.

✓ The overall leaching profile remained stabilised in all the three stages of scale up.

✓ Bioleaching time was reduced from 30 days to as low as 6 and 9 days for copper and zinc respectively with overall increased percent metal extraction.

✓ The comparative metal extraction rate ratio between LSTR and PSTR came down from 1.43 and 1.6 to as close as 1.05 and 1.07 for copper and zinc respectively after adaptation of the consortium to reactors.

✓ The reshuffling experiments were successfully scaled up from shake flask to LSTR level and from LSTR to PSTR level.