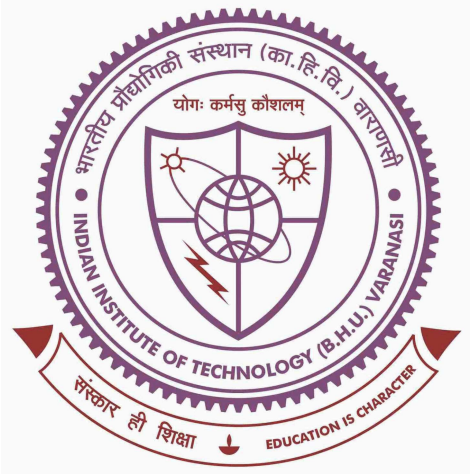
COAL CHARACTERIZATION AND ITS RELATION TO QUALITY AND OCCURRENCE OF RARE EARTH ELEMENTS



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Award of Degree

Doctor of Philosophy

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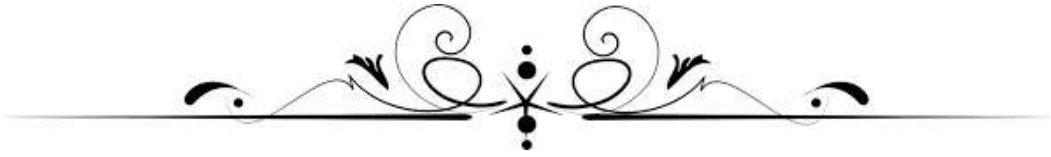
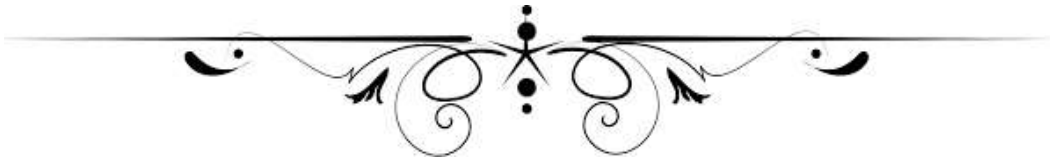


Chapter-10
Conclusions and Suggestions for future work



Chapter 10

Conclusions & Suggestions for Future Work

10.1 Conclusions

The study concludes that the there is wide variation in coal characteristics of the study area. The occurrence of rare earth elements and trace elements in coal, coal by products and coal ash is also showing significant concentration. The important conclusions are given below:

- The megascopic analysis concludes that the Dhanpuri OCM, Sohagpur coalfield, Madhya Pradesh, India region dominantly comprises several bands. Banded coal was found in most of coal samples and Dull coal was found in least coal samples of the study area.
- The rank of the coal is classified as Medium Volatile Bituminous Coal as the volatile matter content ranges from 15.98 to 36.36 percent in coal of the study area.
- The ash content in coal is ranging from 9.65 to 34.21 percent with an average of 16.95 percent in coal of the study area.
- Coals of the study area are suitable for thermal grade coal of G-6 grade.
- GCV of coal of the study area is ranging from 3438 kcal/kg to 6743 kcal/kg with an average of 5726 kcal/kg. Hence, average grade of coal is G-6 grade.
- Carbon content is ranging from 51% to 75% with an average of 63% in coal of the study area.
- The surface morphology of coal on micron level shows that framework grains and matrix were angular, lath shaped, variable size and rough in appearance.

- The XRD study confirmed the presence of important minerals such as quartz, kaolinite, monazite, feldspathoid, anatase (rutile), iron oxide (hematite), birnessite, graphite and gypsum in coal samples of the study area. Kaolinite and illite are the major mineral of clay group found in coal samples.
- The FTIR study also indicated montmorillonite minerals along with kaolinite and illite of clay group. Further, the FTIR spectra also show peaks at 2920 cm^{-1} indicates the presence of long aliphatic chains in these coal samples.
- The concentrations of some trace elements (Cr, Co, Ni, Mo and Pb) are significantly higher. The concentration of Cr, Co, Ni, Mo and Pb are 78.91, 14.42, 19.42, 11.96 and 16.92 ppm respectively. These values are higher than the Clarke values for hard coal samples.
- The concentration of trace elements particularly rare earth elements are found in appreciable quantity in coal of study area as supported by energy dispersive x-ray of the scanning electron microscope also.
- The concentration of different REEs in coal and shaly coal is ranging. The average concentration of all REEs in coal is 9.96 ppm. The lowest average value is 0.2 ppm for lutetium and highest 58.15 ppm for cerium.
- The average concentration of REEs in ash of shaly coal is 27.72 ppm and in coal ash is 40.81 ppm. The lowest average value is 0.59 ppm for lutetium and highest 187.37 ppm for cerium. The maximum concentration of cerium was 237.98 ppm in coal ash of the study area.
- The concentration of REEs in coals of the study area is also compared with coals of the other countries. It shows regional characteristics, i.e., the average concentration of REEs in the coal sample is higher than the US coal. However,

when the data is compared with Chinese coal, Dhanpuri OCM, Sohagpur coalfield also shows higher concentration (in Sc, Y, La, Ce, Pr, Nd, Sm, Eu, and Gd) except for fews (in Tb, Dy, Ho, Er, Tm, Yb, and Lu). When these coal samples were compared with world average value in coal, every REE comes under their range.

- The distribution and abundance of REEs in ash of coal and shaly coal are almost three times higher than the coal of the study area, which is more than the average concentration found in coal of China, USA and also with world coal average.
- The occurrence of monazite has been observed in coal of the study area through XRD further support the higher concentration of REEs.
- In sequential leaching experiment (water and acid) on coal conclude that manganese, zinc, and cobalt are more susceptible to leach with water. The concentrations of these elements are relatively high in water leachate. The excessively higher concentration of manganese element in leachate suggests easy leaching by simply water only.
- Further other elements (Zn, Co, I, Cu, Mo, Cr, Pb, Cd, As and Hf) also released into leachate in relatively lesser concentration. The average concentration of Zn, Co, Ni, Cu, Mo, Cr, Pb, Cd, As and Hf in ppm are 3.0, 1.32, 0.99, 1.10, 0.004, 0.92, 0.74, 0.12, 0.008, 0.0002 respectively.
- The batch leaching of coal with acid of different molarity concludes that higher molarity (2.5 *M*) acid release the trace metals from coal to a maximum concentration. The concentration of manganese is 25.91 ppm in acidic leachate.
- In acidic leaching, all the trace elements performed differently. With the help of experimental results, it can be suggested that the acidic leachate samples (Final acidic water average= FAWA) have a higher concentration than the water leachate

samples (Final water average= FWA). Recovery of manganese is highest and lowest for hafnium in acidic leachate samples.

- With the help of this experiment one, it can be said that the higher the molarity of the acidic solution, the higher the recovery of REEs will be.
- HREEs have higher Pearson coefficient correlation than LREEs in acidic solution.
- With the help of micro-photographs, coal samples became rounded and smooth after leaching experiments and developed bumpy-like structures.
- Every experimental work was performed in possible natural conditions. So in this experimental work (experiment one), there were a few limitations also. These limitations include that only one acid was used for leaching. Only one particle size of coal was used in the experiment. Only one type of sample (coal) was used in the experiment, while there is evidence that coal by-products (CCP) are also a considerable resource for REEs. This experimental setup was performed in the presence of sunlight, so the temperature was not constant during the experiment. Result of this experiment encouraged to conduct another experiments on coal and coal by-products with slight modifications.
- The leaching of coal and calcined coal with acid given better result than non-calcined samples. The concentration of cerium is 73.67 ppm which is one and half times higher than normal sample in coal.
- It may also be concluded from the experiment result that recovery of REEs through leaching from coal is much higher than shaly coal as shaly coal contain higher concentration of strategic REEs than coal.

- The calcined samples have a higher recovery than raw samples. Recovery of REEs was significantly improved by calcinations before leaching. However, without any calcinations, the REEs recovery was relatively low.
- Recovery of LREEs is higher than HREEs from coal and shaly coal.

10.2 Suggestions for future work

The future prospects of the study may include:

1. There is need to develop suitable eco-friendly leaching chemical to recover toxic, valuable and strategic rare earth elements from coal, co-product and its by-products.
2. The proximate and ultimate analysis of coal and shaly coal after leaching is to be conducted to know the changes in the heat value of the coal.
3. A detailed techno-economic aspect of recovery of elements from coal is to be studied.
4. Qualitative and quantitative study of REEs in coal and coal by product in other coalfields of India is also to be studied.
5. Possibility of recovery of REEs from coal and coal by-products by other methods such as bio-leaching has to be investigated as chemical treatment of coal and its by-products may lead to more contamination to environment.