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Development of an enhanced calcination, optimised leaching process for the improved recovery of rare earth elements from South African discard coal

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ABSTRACT

Globally there has been a rapid surge in demand for rare earth elements (REE) due to their numerous high-tech applications. China holds more than 43% of global conventional REE reserves and supplies 97% of the world's REE. Research into other sources of REE is important in responding to society demands, coupled with China's REE export restrictions and unique commodity applications. Mechanised mining in South Africa produces about 60 million tonnes of coal discard each year that is left in discard dumps. Thus, there is an innovative need to reuse discard coal to reduce its pollution and impact on the health of society and the environment.

In this study, a Run of Mine (ROM) and discard coal were evaluated for their REE contents, distribution and association with the inorganic mineral and organic coal constituents. The Tescan Integrated Mineral Analyser was used to investigate the REE associations and distributions. X-ray diffraction provided information on mineral phases and Inductively coupled plasma-mass spectrometry was used to quantify the amount of REE in the coals and subsequent leachate samples. Varying lixiviates under the optimised leaching parameters were investigated using the response surface methodology (RSM) to recover REE from the coal samples. The data attained was used to optimise the leaching process to improve the REE leaching recovery. The same optimised leaching approach was applied to coal samples calcined between 500 ^{o}C to 800 ^{o}C.

The Total REE (TREE) content of each of the two medium rank C bituminous coal samples exceeded 225 ppm. In addition, kaolinite, pyrite and hematite were the main REE-bearing minerals in the discard and ROM coal samples. Heavy REE (HREE) showed a weak ion-adsorbed association with clay minerals (kaolinite) finely dispersed in the organic matrices and fractures of both samples. Furthermore, HREE displayed a strong affinity for the organic macerals and were slightly enriched in the ROM coal, with the discard coal containing higher concentrations of TREE. The encouraging results of this study suggest that both coal sources contain more Critical REE than Uncritical REE, which are in greater demand internationally.

The optimised leaching experiments for both coals indicated that an increase in lixiviate concentration (0.5 M to 2 M) and leaching temperature (30 ^{o}C to 50 ^{o}C), along with a decrease in solid:liquid ratio (40 g/l to 10 g/l), improved the percentage (%) recovery of REE. The RSM and statistical analysis of the leaching data were satisfactorily indicated by an error % of less iii

than 1.26%. The optimised leaching parameters (2 M, 10 g/l and 50 ^{o}C) manifested a 18.95% REE recovery and 41.35% TREE recovery in the discard and ROM samples, respectively. The low recovery of REEs on the raw samples had indicated that significant quantities of the weekly ion adsorbed REEs were recovered. The study indicated that the best lixiviate was HCl, as it achieved a higher REE recovery than $HClO_4$ and is relatively inexpensive compared to HNO_3.

The % REE leaching recovery increased as the calcination temperature increased from 500 ^{o}C to 700 ^{o}C, with optimal calcination at 700 ^{o}C. At this temperature (700 ^{o}C), the REE leaching recovery achieved was 94.73% (ROM) and 98.17% (discard). Calcination also increased the concentration of REE for ROM sample from 225 ppm to 347 ppm and discard sample from 245 ppm to 363 ppm at 700 ^{o}C. At 800 °C, the REE concentration increased to 362 ppm (ROM) and 390 ppm (discard). Leaching time was reduced as the majority of the REE were recovered under the optimised leaching conditions in the first 15 minutes of the process. The significant effect of calcination on REE recovery suggests that REE-bearing minerals were solubilised and oxidised during calcination.

The discard coal used in this study had a significantly higher potential than the ROM coal for REE recovery, as it had higher REE abundance and greater recovery. It also establishes a potentially economically viable secondary REE source as no mining is required and contributes to the international pollution reduction target.