GREEN METALLURGICAL APPROACH FOR VALORISING IRON ORE OVERBURDEN USING BIO-CHAR REDUCTANTS.

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Introduction:
The global steel industry is one of the highest contributors to industrial CO_2 emissions, primarily due to the heavy reliance on coke and coal for iron ore reduction. As high-grade iron ore reserves deplete, the industry is forced to look toward low-grade ores like Banded Hematite Quartzite (BHQ), which are often discarded as overburden or "waste" during mining operations. These materials occupy vast land areas and pose environmental risks.
Simultaneously, India generates millions of tons of agricultural residues, such as groundnut shells, which are often burnt openly, causing air pollution. This project integrates these two problems into a single circular economy solution. By converting groundnut shells into bio-char through pyrolysis, we create a renewable, carbon-neutral reductant. Unlike fossil fuels, bio-char contains fewer impurities like sulphur and phosphorus. The core concept involves "Reduction Roasting," where the non-magnetic hematite in BHQ is converted into magnetic magnetite using bio-char. This transition allows for high-efficiency recovery using magnetic separation. This research explores the synergy between green chemistry and extractive metallurgy, aiming to transform low-grade mineral "waste" into a high-value industrial resource while significantly lowering the carbon footprint of the pre-treatment process.

Figure 1: Iron ore (Overburden) disposal in Mines, G Shell waste and energy footprint & Sample Collection.

Objectives:

1. To characterize the raw BHQ overburden through size analysis (Particle size distribution) and Fe% determination.

2. To produce bio-char from groundnut shells via pyrolysis at controlled temperatures (500°C, 550°C, and 600°C).
3. To analyse the chemical and structural transitions of the Groundnut Powder using Proximate Analysis and FTIR.
4. To perform reduction roasting experiments on BHQ using varied bio-char dosages (10% and 20%) and temperatures.
5. To evaluate the efficiency of magnetic separation in upgrading the iron content.
6. To compare the pre-roasting and post-roasting Fe grades to determine the enrichment factor.
7. To identify the optimum temperature and dosage parameters for maximum Fe recovery and cost-efficiency.

Methodology:

Phase I: Feedstock Preparation and Characterization

The research commenced with the acquisition of iron ore overburden, specifically Banded Hematite Quartzite (BHQ), To ensure statistical reliability, the bulk sample was homogenized and reduced through coning and quartering methods to obtain a representative 5kg subset for analysis. A detailed sieve analysis was performed to establish the particle size distribution, while the initial chemical composition specifically the total iron content (Fe%)—was determined through titrimetric analysis to establish a baseline for the enrichment ratio.

Phase II: Thermochemical Reductant Synthesis

The "Green" aspect of the process involved the conversion of agricultural residue into a high-efficiency metallurgical reductant. Groundnut shells were collected, cleaned of debris, and subjected to pyrolysis within a muffle furnace under an inert or oxygen-limited atmosphere. The carbonization was executed at three distinct thermal regimes: 500°C, 550°C, and 600°C, with the resulting charcoal yields recorded at approximately 29%, 28%, and 30% respectively. To evaluate the quality of the bio-char, proximate analysis was conducted to determine fixed carbon and volatile matter, while Fourier Transform Infrared (FTIR) Spectroscopy was utilized to track the chemical transition from raw biomass to carbonized reductant, specifically monitoring the degradation of aliphatic functional groups.

Phase III: Reduction Roasting (Magnetizing Roasting)

The core metallurgical treatment involved solid-state reduction roasting to transform non-magnetic hematite and goethite into a magnetic magnetite phase. 100-gram charges of BHQ were blended with the synthesized bio-char at specific reductant-to-feed ratios (0.1 and 0.2). A total of six experimental trials were conducted, varying the roasting temperature and dosage to optimize the kinetic environment. During this phase, the carbon in the bio-char acted as a reducing agent, facilitating the oxygen stripping process required to increase the magnetic susceptibility of the iron minerals.

Phase IV: Beneficiation and Enrichment Analysis

Following the roasting process, the calcined material was subjected to Bar Magnet Separation (a form of Low-Intensity Magnetic Separation) to isolate the newly formed magnetic concentrates from the siliceous gangue. The magnetic and non-magnetic fractions were weighed to calculate the mass yield. Finally, a post-experimental Fe analysis was performed on the concentrate to evaluate the grade improvement and metallurgical recovery. These results were comparatively analysed against the raw feed data to identify the optimum temperature and dosage parameters for maximum cost-efficiency and upgradation.

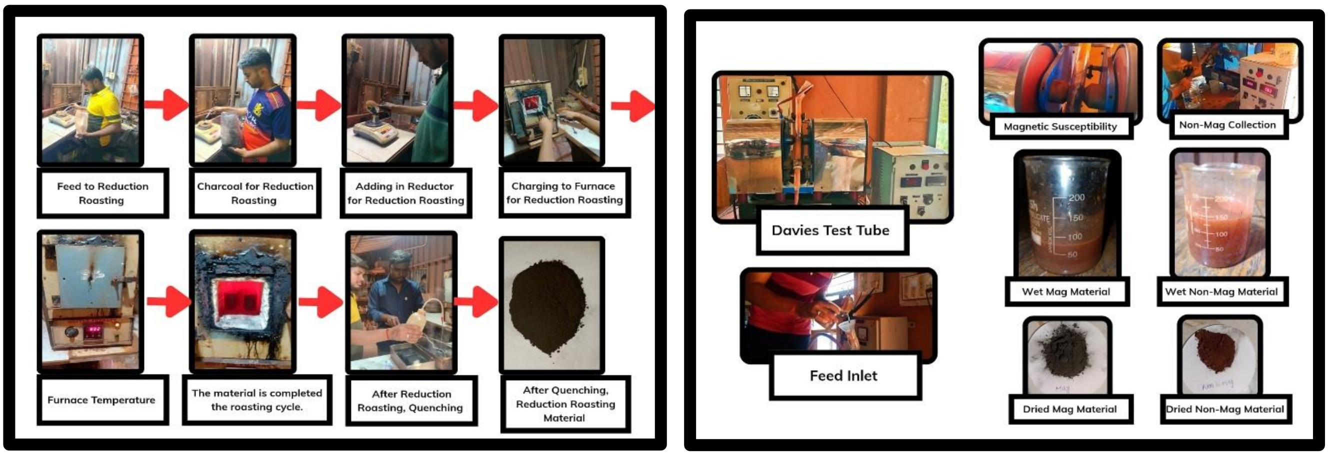

Figure 2: Following Experiment Methodology Process.

Result and Conclusion:

The experimental data for the reduction roasting of BHQ iron ore at a constant temperature of 900°C reveals a clear correlation between residence time and the efficiency of the metallurgical upgrade. As the roasting time increased from 30 to 60 minutes, the iron (Fe) grade of the magnetic concentrate (Mag) showed a steady improvement, rising from 53.02% to 57.5%. This enhancement suggests that a longer residence time at high temperatures facilitates a more thorough conversion of hematite into magnetic magnetite by allowing the bio-char reductant more time to react with the ore matrix. Interestingly, while the weight percentage (Wt.%) of the magnetic fraction slightly decreased as time progressed, the Fe recovery percentage increased from 59.9% to 63.9%, indicating that the process became more selective in isolating iron values from the gangue.

The Fe grade in the non-magnetic tailings (N Mag) simultaneously dropped from 21.02% to 18.6%, further confirming that more iron was successfully migrated into the magnetic product during the 60-minute trial. These results imply that for BHQ overburden, a 60-minute roasting period at 900°C provides the optimal balance of high grade and high recovery. This performance is likely attributed to the superior reactivity of the groundnut shell bio-char, which maintains its reducing potential effectively over extended periods at high temperatures.

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Future Scope:

1. **Pelletization and Sintering Studies:** Future research could focus on the micro-pelletization of BHQ with bio-char. By creating composite pellets before roasting, the intimate contact between the reductant and the ore can significantly enhance reaction kinetics and reduce roasting time.
2. **Scale-up to Rotary Kiln:** While current experiments are batch-scale in a muffle furnace, the next logical step is to test the process in a pilot-scale rotary kiln. This would simulate continuous industrial production and help determine the "residence time" required for large-scale operations.
3. **Optimization of Pyrolysis Gas:** The volatile matter (bio-gas) released during the pyrolysis of groundnut shells at 550°C–600°C could be captured and used as a fuel source to heat the roasting furnace, creating a self-sustaining energy loop.
4. **Tailings Valorisation:** The non-magnetic waste (tailings) generated after separation is high in silica. Future studies could investigate using these tailings as raw material for geopolymer bricks or as a partial sand replacement in construction, aiming for "Zero Waste" mining.