# Synopsis of the Research Work

# Enrichment of Low Grade Chromite Ore for the Recovery of Metal Values for Suitable Value added Product

**Thesis Submitted**
**by**
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## Introduction

Chromium is a critical and versatile element widely utilized in both ferrous and non-ferrous industries, with chromite being its sole commercially valuable ore. Renowned for its strategic importance, chromite is a key raw material for producing alloy steels, ferrochrome, chrome-metal, and various alloys with elements like nickel, cobalt, and molybdenum. Chromium significantly enhances the strength, hardness, corrosion resistance, and oxidation resistance of alloys, making it indispensable for metallurgical and chemical applications. However, global reserves of high-grade chromite are rapidly depleting due to escalating demand, while deposits of high-grade ores are geographically limited. India, in particular, holds substantial reserves of low-grade chromite ore, with around 23% of its chromite reserves characterized by low Cr:Fe ratios, rendering direct extraction economically unviable. Efficient utilization of low-grade chromite requires innovative beneficiation techniques, combining physical and chemical processes. Gravity separation methods such as jigging, heavy media separation, and shaking tables are promising for physical beneficiation. Chemical methods like acid and base leaching, albeit costly, can be made economical and environmentally friendly through proper waste treatment and recycling.

## Objective

The objective of this research is to develop and optimize process technologies for the effective utilization of low-grade chromite ore and fines to recover valuable metals. This study aims to address the challenges posed by declining high-grade deposits and rising demand for chromium-based products. It focuses on pyrometallurgical and hydrometallurgical methods to enhance the economic viability of low-grade ore. The ultimate goal is to support domestic ferrochrome and steel production while ensuring profitability and environmental sustainability.

## 1. Experimental Work

### 1.1 Characterization of Chromite Ore, Reductants, and Binders

The characterization of chromite ore in this study is conducted using various advanced analytical instruments, including an Atomic Absorption Spectrophotometer (AAS), Thermogravimetric-Differential Thermal Analyzer (TG-DTA), Wavelength Dispersive X-ray Fluorescence

Spectrometer (WDXRF), X-ray Diffraction (XRD), and Scanning Electron Microscope (SEM). The collected chromite ore is identified as low-grade, comprising $Cr_2O_3$ (26.88%), $Fe_2O_3$ (33.88%), and $Al_2O_3$ (21.08%), with berezovskite ($(Mg,Fe)(Al,Cr)_2O_4$) as the primary mineral phase. Coke and boiler-grade coal are utilized as reductants, while molasses and bentonite are assessed as binders, with molasses exhibiting superior adhesive properties. Thermal analysis indicated significant phase transitions occurring between 300°C and 350°C.

### 1.2 Upgradation of Chromite Ore

The declining availability of high-grade chromite ore and the underutilization of chromite fines pose significant challenges. This study introduces a novel heating and air-quenching technique to induce fissures in low-grade chromite ore, enhancing mineral liberation and beneficiation using a wilfley table. Parameter optimization through the Box-Behnken Design (BBD) improved the Cr/Fe ratio from 0.78 to 2.17, with a recovery of 70.08%. Optimal conditions included a tilt angle of 8°, a water flow rate of 4 L/min, and a pre-heating temperature of 443.72°C. Pre-heating effectively generated cracks and fissures, significantly aiding $Cr_2O_3$ recovery.

### 1.3 Agglomeration and Briquetting

The study investigates chromite beneficiation using a wilfley table, followed by briquetting with different binder proportions and pressures to optimize reduction and metal recovery. The optimal briquette composition includes 3% bentonite, 3% molasses, 3% water, and a briquetting pressure of 450 kg, resulting in enhanced mechanical strength and reducibility. Mechanical properties improved with increased briquetting pressure, while lower binder percentages contributed to better reducibility.

### 1.4 Isothermal Reduction of Chromite Briquettes

Low-temperature reduction of chromite briquettes is conducted in a tubular furnace with controlled heating and air quenching, followed by weight loss measurement to determine the extent of reduction (EOR). High-temperature reduction is carried out in a raising hearth furnace, where briquettes are periodically exposed to lump coke to maintain a reducing atmosphere, and the reduced samples are characterized by XRD and SEM. The reduction studies revealed chromium metallization above 1573K, with maximum metallization of 75.50% (Cr) and 75.71% (Fe) at 1723K over 120 minutes. The reduction mechanism shifted from CG2 to D3, with activation energies of 165.36 kJ/mol and 179.36 kJ/mol, respectively. The smelting process produced ferrochrome containing 52.96% chromium and 28.72% iron, with the slag phases enriched in silica and alumina.

### 1.5 Reduction in a Gasification Furnace

Low-grade chromite ores from Sukinda mines, containing less than 30% chromium oxide, are processed to produce ferrochrome through crushing, pelletizing, and firing at 1473K. After reduction, magnetic separation and aluminothermic reduction are employed, with the enriched materials characterized using AAS, XRD, and SEM. Pre-reduction at 1473K using lean-grade coal improved the Cr/Fe ratio from 0.775 to 1.18, and XRD and SEM analyses confirmed phase evolution and the lamellar structure of the resulting ferroalloy.

### 1.6 Hydrometallurgical Treatment

Low-grade chromite ore is processed through crushing, grinding, and oxidative roasting with sodium nitrate and sodium hydroxide at varying temperatures and times to examine the dissolution process. Leachates are analyzed by AAS, while residues are characterized by XRD and SEM; chromium recovery of 99.52% is achieved, following a D5 kinetic mechanism with an activation energy of 48.38 kJ/mol. The residues mainly consist of $Fe_2O_3$, MgO, and $Al_2O_3$, and the purity of potassium dichromate produced reaches 90.76%.

## 7. Bioleaching of Chromite Ore

In the bioleaching process, Pseudomonas putida is cultured in Luria broth medium at 37°C for 48 hours. Experimental setups with varying pulp densities and culture volumes are designed to assess bioleaching efficiency, with chromium, iron, and aluminum concentrations determined via atomic absorption spectroscopy (AAS). Bioleaching with Pseudomonas putida effectively leached aluminum at low pulp densities, while the spinel structure hindered chromium and iron leaching. However, bacterial activity enhanced aluminum solubilization.

**Summarized Observation:**

The analysis identifies the ore as low-grade chromite with a Cr/Fe ratio of 0.78, major constituents being $Cr_2O_3$ (26.88%), $Fe_2O_3$ (33.88%), and $Al_2O_3$ (21.075%), and a spinel structure dominated by berezovskite. Gravity separation using a wilfley table, optimized via Box-Behnken Design, enhances the Cr/Fe ratio to 1.91 and achieves a $Cr_2O_3$ recovery of 65.95% under optimal pre-heating and operational conditions. Briquetting with 3% bentonite, 3% molasses, and 450 kg pressure improves mechanical strength and reducibility for ferrochrome production. Chromium and iron reduction peaks at 75.50% and 75.71%, respectively, at 1723 K. Oxidative roasting achieves 99.52% chromium recovery, while bioleaching using *Pseudomonas putida* effectively removes aluminum but is limited for chromium and iron due to the spinel structure. These findings confirm robust strategies for upgrading chromite ore for industrial applications.

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